Table 3: Results of analysis of the investigated soil profiles.

No.	Site (map coordinates)	Lithotypes	Profile depth (cm)	Soil class	Coarse fragments (% vol.)	Soil color (when moist)	Bulk density (g/cm^3)	Soil moisture (% weight)	nFK (mm)	pH (0,1n) (KC1)	CaCo^2 (%)	C	Humus (%)	P_2O_5 (ppm)	K_2O (ppm)
P 1	Bayt al Mugh.	TU 20	0 - 30	loamy sand	20	LOYR3/3	1.34	3.70	38	7.3	8.5	1.0	1.7	58	148
	(62.30/65.40)		30 - 60	loamy sand	25		1.35	4.60	36	7.4	8.9	0.9	1.6	40	90
P 2	Jabal Shibam	(ET 16	0 - 30	loam	15	IOYR4/1	1.34	8.20	43	6.8	1.0	0.8	1.4	42	104
	(63.70/64.40)	ET 15)[1]	30 - 60	loam	25	IOYR3/3	1.21	8.80	38	6.7	0.5	0.9	1.6	48	116
P 3	Kahil	TY 7	0 - 30	sandy loam	10	IOYR4/3	1.40	-	51	7.6	0.9	0.5	0.8	239	243
	(64.85/64.95)	ET 8	30 - 60	sandy loam	15	IOYR4/3	1.42	-	48	7.4	1.5	0.3	0.5	197	170
P 4	Westl. Kahil	(TU	0 - 35	silt loam	40	IOYR3/3	1.35	-	45	7.1	0.4	1.5	2.6	44	146
	(64.20/65.95)	9a/b)[1]													
P 5	Bayt Hamid	-	0 - 30	sandy loam	25	IOYR4/3	1.38	5.75	43	7.4	0.5	0.8	1.3	216	298
	(62.90/64.55)		30 - 60	loamy sand	30	IOYR4/3	1.45	5.91	34	7.4	0.8	0.4	0.6	104	148
P 6	East of Kahil	(TY 6)[1]	0 - 30	loamy sand	25	IOYR4/2	1.38	4.84	36	7.5	1.0	1.0	1.7	186	219
	(64.80/65.65)		30 - 60	sandy loam	30	IOYR4/3	1.33	6.56	40	7.6	1.5	0.7	1.2	232	85
P 7	Above Kahil	(TU	0 - 30	silt loam	40	IOYR4/3	1.30	-	39	7.2	0.4	1.5	2.7	29	160
	(64.65/65.10)	9a/b)[1]	30 - 60	sandy loam	50	IOYR3/3	1.30	-	29	6.8	0.3	0.9	1.5	26	71
P 8	Ashami field	-	0 - 30	sandy loam	25	IOYR4/3	1.30	6.48	43	7.3	0.8	0.6	1.0	50	77
	(63.05/66.15)		30 - 60	sandy loam	40	IOYR3/3	1.40	7.95	34	7.4	0.7	0.9	1.5	61	85
P 9	Manakhah	TY 3	0 - 30	sandy loam	50	IOYR4/2	1.40	12.68[2]	29	7.6	3.6	1.6	2.7	73	275
	(64.75/67.65)		30 - 60	sandy loam	10	IOYR4/2	1.40	6.02	51	7.7	2.3	0.7	1.3	63	157
P 10	Manahkah	IG 5	0 - 30	loam	25	IOYR4/3	1.27	7.00	38	7.6	1.5	0.7	1.3	152	385
	(64.45/67.45)		30 - 60	clay loam	35	IOYR4/3	1.43	9.70	29	7.6	1.7	0.5	0.8	55	168
P 11	Manakhah	(IG 5)[1]	0 - 30	loam	20	IOYR4/2	1.38	6.22	41	7.7	3.3	0.7	1.2	352	424
	(64.25/67.10)		30 - 60	clay loam	20	IOYR4/2	1.59	11.35	29	7.7	4.5	0.4	0.6	92	415

1( ) = Certain rocks not from site

2 RIt had rained the night before (11.1 mm recorded at Manakhah station on 9/9/84)

IV. Soil erosion in the study area

1. Socioeconomic background

During the last two to three decades, former North Yemen had experienced profound political and socioeconomic changes.

When the 7-year civil war came to an end in 1969, leaving North Yemen as a firmly consolidated republic, and the country opened itself to complete integration into the global economy, massive emigration of workers to the neighboring oil-producing states began (Kopp 1985, p. 46). Between 1970 and 1980 this manpower drain, provoked by the higher wages in the oil-producing countries, affected more than a third of the male population hitherto employed in agriculture, reducing its number from a previous level of 1 million to less than 700,000 (Steffen 1981, p. 73). During the same period, the number of Yemeni guest workers in the oil-producing countries of the Arabian peninsula - at an official population of 5,750,000 (1979/80) - rose from roughly 140,000 to 520,000 (Steffen 1981, pp. 75 and 79). Other sources place the number of North Yemenis working abroad on a short-term basis at that time at up to a million (Statistisches Bundesamt 1985, p. 28).

According to the census conducted in 1975, the Manakhah district has been affected more severely than most areas by this rural exodus. Thus, in 1975 the emigration rate[5] in the study area was 8%, i.e. at a total population of 34,919 persons (16,192 men) 3,036, corresponding to around 19% of the total and over 40% of the employable male population, were working in other countries (Steffen 1979, pp. 162 and 165-166). These figures have increased further since then, as is vividly illustrated by the abandonment and degradation of the village and fields of Bayt Hamid at the beginning of the 1980s (cf. maps).

As a result of the labor shortage which this development has caused in the agricultural sector, during the course of the 1970s the total farmed area in North Yemen was reduced by about 30%. The vast majority of the fields abandoned during this time were in mountainous areas like the Haraz, in which great effort had been put into terracing the slopes (cf. Land-Use Map). Grain-growing (sorghum, wheat, barley), which is for the most part

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5) Emigration rate = individuals working abroad x 100 / total population + individuals working abroad

dependent on rain-fed irrigation, has been the most seriously affected. Growing of these crops as a source of livelihood is not only unable to compete with the high wages in the oil-exporting states, but due to its lack of profitability (the ratio of labor input to yields) is also increasingly at a disadvantage vis-à-vis imported foodstuffs, in spite of the high esteem in which domestic products are held (Steffen 1981, pp. 76 and 80; Varisco 1982, pp. 218-220).

In the final analysis, the issue around which the entire problem revolves is the enormous relief-related labor input required for terrace farming, on account of which virtually only irrigated qat cultivation now guarantees reliable yields and above all a sufficient level of profitability within the context of the currently prevailing general economic conditions (cf. Alkämper et al. 1979, pp. 93-94). In future, however, it will be impossible for qat production to continue expanding at the rate which has been observed since the end of the civil war (Kopp 1985, p. 48), due to competition for the limited water resources, which are increasingly needed for domestic consumption, and to saturation of the market - which is already gradually making itself felt. In the study area, erosional processes provoked by minimization of labor inputs and expenditure or complete abandonment of terrace farming have already caused irreversible destruction of many parts of this landscape, which was domesticated over the course of centuries. This process must be designated as irreversible, since restoration of terraces once they have been destroyed is impossible within the scope of humanly relevant time spans, i.e. 20 to 30 years.

Nonetheless, changing global economic conditions make it appear quite possible that one day former North Yemen will be confronted by the return of its labor migrants from abroad. In this predominantly agriculturally oriented country, they will then only be able to make a living by farming, in other words by resuming cultivation of the terraces they had previously given up. But once the valuable resources which these terraces represent have been destroyed, the ability of these mountainous regions to support agriculture will be reduced to a minimum. In spite of these undeniable facts, however, the endangered mountain regions are still being denied adequate consideration by government regional planning and development promotion activities (Kopp 1985, p. 48).

2. The various natural soil erosion factors

a) The erosivity of rainfall and runoff

When conducting application-oriented studies of soil erosion, knowledge of the basic erosion risk posed by the climate is indispensable. If, like in the present case, water erosion is at issue, then useful data on rainfall parameters must be available. And in order to chose which parameters to consider, a detailed understanding of their functions is required, i.e. it is necessary to have a clear idea of the erosive phenomenon under study and its dynamics.

In the case of soil removal by splash, sheet and rill erosion, the kinetic energy of the falling raindrops has proven to be the most important factor. When corresponding data is available (on rainfall intensity and precipitation), this can be calculated with the aid of empirical erosivity indices (see section 3 b of this chapter). In the present study, the KE>25 index developed by N. HUDSON (1981) has been applied, preference being given to it over the EI_{30} index of W. WISCHMEIER and D. SMITH (1978) for three reasons. The main reason is that N. HUDSON developed his erosivity index in outer tropical Africa (Zimbabwe), a fact which justifies the assumption that it represents a suitable tool for measuring the detachment potential of high-intensity tropical rains (Morgan 1979, p. 17; Morgan et al. 1982, p. 73). In addition, this index is simpler to compute and does not require such a large body of precise recording rain-gage data as the EI_{30} index, which is calculated from two different empirical factors (cf. Morgan 1979, p. 20; Hudson 1981, pp. 68-70; Schieber 1983, p. 91). If it is necessary to base the calculations on weekly precipitation data with low temporal resolution, as in the present case, then this represents a major advantage.

The data used for this purpose was collected between the beginning of 1983 and the middle of 1985 by standard Hellmann recording rain gages at the Manakhah weather station and the Ashami field (63,05/66,15). The paper strips on which the amount of precipitation collected was recorded advanced at a rate of only 55 mm per day, corresponding to a low temporal resolution. Thus, 4.6 mm correspond to two hours, 1.15 mm represent 30 minutes, 1 mm corresponds to 26.1 minutes and half a millimeter represents 13 minutes. In view of this low temporal resolution, problems inevitably arose in connection with determination of both rainfall intensity and the amount of precipitation.

In the case of cloudburst-like high-intensity rainfall, for example, the virtually vertical markings made by the recorders were so close together that even with a filar micrometer it was not always possible to reliably measure the exact amount of precipitation. Since such cases are associated with possible errors on the order of 10 mm, in future it is absolutely essential for the total amounts of accumulated precipitation in the measuring receptacles to be entered in a book when changing the paper strips each week.

Determination of rainfall intensity proved to be even more problematic and, above all, extremely time-consuming. In the end, this could only be done precisely using a filar micrometer and two 90°-45°-45° set squares (triangles) (cf. Schmidt 1983, p. 59). One set square was placed horizontally on a recording strip with the 0 mark of its long side at the starting point of the section for measurement, while the second set square was placed vertically on top of it. Determination of the end point was then performed with the micrometer.

In order to measure the rainfall intensities as accurately as possible, priority was attached to measuring the erosive high-intensity rainfall sections of the precipitation events, within the range of 0.5 to 1 mm. Since all of the measured values were slightly less or slightly more than this range, in 80-85% of all cases a finer differentiation was performed on the order of 10, 15 or 20 minutes, while the remaining calculations were based on periods of 25 and 30 minutes. Only in 5 exceptional cases, in which it was possible for rainfall intensity to be determined with a truly reliable degree of accuracy, was a very fine breakdown into 5-minute intervals (0.19 mm) performed. This approach proved to be very practicable, since the proportion of erosive high-intensity rainfall per storm event nearly always lasted between 10 and 30 minutes.

The evaluations of the data from the 2 1/2-year observation period confirmed that the study area is characterized by the high climate-related risk of erosion typical of the tropics (cf. Hudson 1981, pp. 78-79).

The two weather stations yielded a quite consistent overall picture. It is conspicuous that the yearly (for 1983 and 1984) and half-yearly (for the first 6 months of 1985) averages for the investigated parameters remained within a uniform, relatively narrow band. For example, it emerged that 49 to 64% of the yearly and half-yearly total rainfall of between roughly 340 and a maximum of about 430 mm is erosive, i.e. exhibits an intensity of 25 mm/h or more (cf. T. Moore 1979, p. 150; Lal et al. 1980, p. 144). The average duration of erosive high-intensity rainfall is 15-20 minutes, delivering an average amount of precipitation of 11-13 mm at an average intensity of 35-45 mm/h. The overall yearly and half-yearly erosivity is, at an average kinetic

energy of 26.5 J/m^2 per mm of rain, between 4,400 and 5,900 J/m^2. During brief intervals lasting between 5 and 15 minutes, peak intensities of between 70 and 90 mm/h can be attained. The maximum duration of high-intensity rainfall can reach one hour in extreme cases, delivering up to 40 mm of rain. Peak erosivities of 800 - 1,000 J/m^2 can occur during such extreme rainfall events, corresponding to 10 to 20% of the yearly total.

An evaluation of these yearly index values within the overall context of the tropics shows that the absolute rainfall erosivity in the study area must be classified as moderate. A mean yearly erosivity of approx. 15,000 J/m^2 is regarded as average in the tropics (temperate latitudes: 900 J/m^2/year), corresponding to an intermediate level between moderate and high erosion risk (Morgan 1979, p. 77; Hudson 1981, p. 79). Apart from the fact that such values are only useful as approximate guidelines, in the case of the study area it must also be taken into account that the evaluated period is comprised of relatively dry years; consequently, long-term erosivity is probably somewhat higher.

Of much greater significance, however, are the mentioned extreme rainfall events and the prominent seasonal pattern of the erosivity regime (see Fig. 14). For example, in 1983 and 1984 data from both of the recording sites showed that between 37 and 55% of the total yearly erosive high-intensity rainfall was concentrated in a single month, namely in April (1983) and May (1984), at the beginning of the rainy season. Since at this early time of year the plant cover on pasture areas and abandoned terrace complexes has not developed sufficiently to afford adequate protection, the unbound and desiccated surface of the soil is subjected to the unmitigated erosive force of the falling rain. As a result of this, the effective risk of soil erosion must be regarded as much higher than the levels expressed by the annual values (cf. Stocking and Elwell 1976, pp. 15-16).

Conditions comparable to those in the study area as regards concentration of erosivity at the beginning of the rainy season also exist in the dry areas of equatorial East Africa (T. Moore 1979, p. 155). Moreover, these two regions have much in common as regards both absolute erosivity and total annual precipitation.

The studies carried out by T. MOORE (1979), also with the aid of the Hudson index on the basis of measurements over 15-minute intervals, yielded average erosivity values of between 2,300 and 6,000 J/m^2/year at sites with long-term average annual precipitation levels of 200 to about 600 mm. In areas with total annual precipitation of approx. 1,500 mm, erosivity values of around 20,000 J/m^2/year were established.

The conspicuous agreement between the data evaluated for the two weather stations in the study area on the one hand and the data from the climatically comparable sites in semiarid Kenya and Tanzania on the other demonstrates that good results can be achieved by careful evaluation, even on the basis of less-than-satisfactory data.

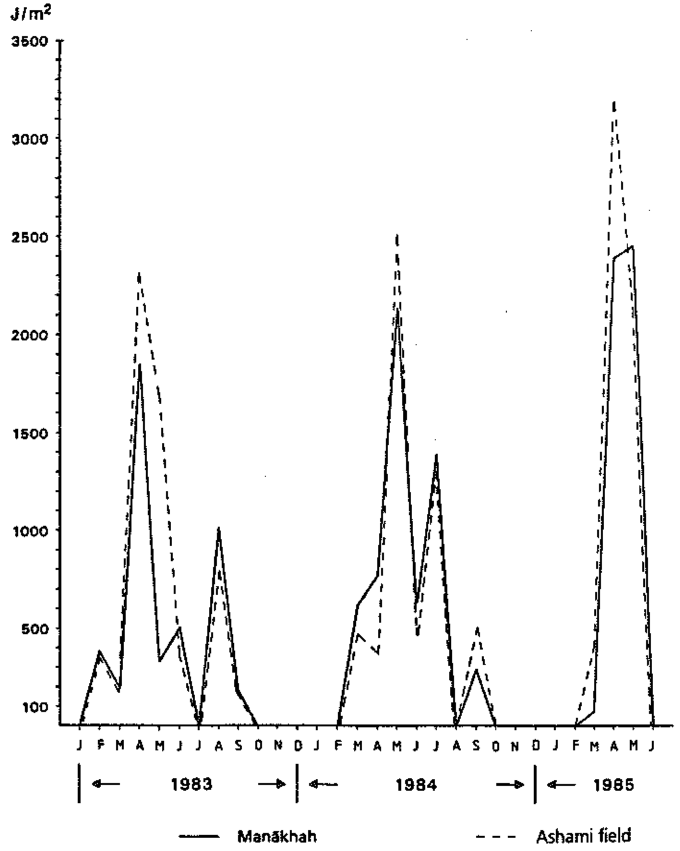
Because a considerable part of the soil destruction in the study area is due to gully erosion, however, the Hudson index alone is not sufficient for providing a picture of the climatically induced, i.e. rainfall-related, danger of erosion. While the erosivity of the rainfall depends on rainfall intensity and the effective amount of precipitation, the erosive power of surface runoff is determined by the relief and the runoff volume, with the latter constituting that portion of the fallen rain that does not infiltrate into the soil. This fact is quite clearly illustrated by the studies conducted in Zimbabwe by M. STOCKING (1978; 1980a), according to which gully growth correlates most closely with total rainfall per storm event, especially when, like in the study area, the gullies work their way upstream by waterfall action at their headcuts (Stocking 1978, pp. 147-149; 1980a, p. 517).

In order to be able to assess the climate-related danger of gully erosion in a given area, therefore, it is necessary to possess information on the maximum amounts of precipitation per day or per hour, as well as the frequency of high-intensity rain (see Table 4a). Since no accepted definition for the onset of gully erosion in terms of rainfall intensity exists comparable to that for sheet and rill erosion (≥ 25 mm/h), in the following an hourly or daily precipitation of 10 mm - a level selected more or less arbitrarily - will be used tentatively as a threshold value above which runoff concentrated in well-defined channels can be expected to occur. This value has demonstrated its usefulness in Central Europe (G. Richter 1978, p. 377; 1983, p. 41), and it can therefore be assumed that such amounts of precipitation can also provoke concentrated linear runoff in regions like the study area, in which the general conditions are much more conducive to runoff (heavy rains, a high relief ratio, structurally unstable soils, lack of vegetal cover). In addition, this value is advantageous for purely pragmatic reasons, since it was also applied by F. FASSBENDER (1982) to the YOMINCO data (cf. Table 4a).

The values listed in Table 4a give a very clear picture of the potential danger of gully erosion in the study area. At least for the time period between the beginning of 1983 and the middle of 1985, between 8 and 12 high-intensity rainfall events accounted for between 53 and 70% of the total yearly and half-yearly precipitation. In the years 1978 and 1979 this concentration appears to have been even more prominent. The greatest amounts of precipitation recorded during a single hour were on August 21, 1983 (38.1 mm), and on May 13, 1985 (36.4 mm). The greatest amounts of daily precipitation were measured in May 1979 (67 mm), and in August of the same year (53 mm) (Fassbender 1982, appendix I, p. 1).

In view of the effects which stream-like surface runoff can have in high-relief areas (see section 3 c), these figures stress the dangers which threaten untended terrace complexes in the study area. The large gully incisions in

Fig. 14: Erosivity regimes at the Manakhah station and the Ashami field.



Design and Artwork: H. Vogel (1985)

abandoned terraces are certainly the result of such high-intensity rainfall events, which in the study area predominantly take the form of brief cloudbursts during the afternoon or early evening and are characterized by both the high intensities and the water volumes required for entrainment and transport of soil material (cf. Roose 1977, p. 62; Heine 1978, pp. 394-397; Semmel 1978, p. 418; Lenthe et al. 1981, p. 38). Information obtained from the interviews conducted during the course of my stay in the field confirms this assumption, as well as the observation that grasses and shrubs (*Ruminex nervosum*) even invade active gullies and the alluvial fans which are frequently located at their mouths, a phenomenon which would be highly unlikely in the case of continuous incision.

Table 4a: Frequency of high-intensity rainfall in Manakhah as an indicator of risk of gully erosion.

Hourly/ daily totals		<10 mm	>10mm	>30mm	Total
1978	1.	26	17	3*	46
	2.			114.0*	531.9
	3.			21*	100
1979	1.	29	11	4*	44
	2.			191.0*	572.1
	3.			33*	100
1983	1.	78	7	1	86
	2.	169.9	154.2	38.1	362.2
	3.	47	42	11	100
1984	1.	63	12	-	75
	2.	131.6	212.8	-	344.4
	3.	38	62	-	100
1985 (up to 6/17)	1.	40	10	2	52
	2.	96	147.9	71.5	315.4
	3.	30	47	23	100

1. No. of events
2. Precipitation in mm
3. Percentage of precipitation

* Minimum values

Source: GTZ Haraz Pilot Project (Manakhah station)
Fassbender (1982, appendix I, p. 1)

According to R. MORGAN (1979), the climate-related threat of gully erosion to a given area can also be assessed with the aid of the index developed by F. FOURNIER (1960).

$$p^{2/P}$$

where:
p = average precipitation of the rainiest month
P = average annual precipitation

The original purpose of this index was to determine the natural (geologic) sediment yield of large watersheds. It is based on the observed agreement between the amount of sediment carried by large African rivers and seasonal concentrations of precipitation. A high index value indicates a prominently seasonal rainfall regime.

The value of this index for assessing the risk of gully erosion is based on the observation that seasonal precipitation regimes characterized by heavy, high-intensity rainfalls are associated with the formation of first-order streams and gullies (Morgan 1979, pp. 72 and 76). For the study area, however, the original version of this index proved to be unsuitable because of the extreme interannual variability of monthly precipitation levels during the observation period.

Nonetheless, the danger of gully erosion in the study area can be quite clearly demonstrated with the aid of the modified version developed by H. ARNOLDUS (1977; 1980), provided that this index is calculated separately for each individual year instead of deriving average values for periods spanning a number of years.

$$\sum_1^{12} p^2/P$$

where:
p = average monthly precipitation
P = average annual precipitation

The results obtained in this way call attention to the extreme seasonal concentration of total annual precipitation, thus providing an impression of the high risk of gully erosion during certain months (see Table 4b).

To sum up, the climate-related risk of soil erosion in the study area can be classified as moderate to high. The moderate long-term risk of sheet, rill and gully erosion over a number of years is offset by a high to very high risk during certain months or even individual high-intensity rainfall events.

Table 4b: Distribution of annual precipitation (p^2/P) as an indicator of the risk of gully erosion.

Year/ Month	1978	1979	1983	1984
January	-	-	-	-
February	-	-	3.6	-
March	-	0.6	1.0	3.7
April	8.7	3.9	*34.5*	3.3
May	11.4	*47.6*	9.5	*50.7*
June	1.4	0.4	1.6	2.1
July	*44.4*	13.5	3.4	14.7
August	14.0	*94.9*	13.5	1.0
September	15.9	0.1	0.1	1.6
October	-	-	-	-
November	0.8	-	-	-
December	0.1	-	-	0.1

b) Erodibility of the soils

ba) Aggregate stability as a measure of erodibility

Surface runoff and soil removal begin in the same moment that rainfall intensity exceeds the infiltration capacity of the soil (see section 3 c of this chapter; cf. Unkel and Endangan 1976, p. 401; Holy 1980, p. 50). The infiltration capacity of the soil is governed by the type and density of vegetation, as well as, above all, soil attributes such as structure and texture, soil moisture (degree of saturation) at the beginning of the rainstorm, and the tendency of the soil aggregates to seal with wetting, i.e. the ability of the soil surface to preserve its structure when struck by falling raindrops and when covered by standing or flowing water. Whether or not and how long the pore structure of the soil, which permits circulation of water and air, remains intact depends on the soil's stability when exposed to water. If the soil aggregates and thus the pore system collapse under the influence of the water, then the soil seals off with the results that conduction and storage of water no longer function (Sekera 1951, p. 57; 1959, p. 9; Weitzenberg 1973, pp. 173-174).

For this reason, aggregate stability has proven to be a valuable indicator of the susceptibility to erosion (i.e. erodibility) of a particular soil, since on the one hand it provides a measure of the risk of surface runoff, and on the other hand indicates the availability of transportable soil material (Bergsma 1985, pp. 1-2).

During the field investigations, the ability of the soil surface aggregates to withstand the effects of water was assessed with the aid of two very simple methods. Every time that it rained during the course of my 10-week stay in the area, immediately afterward I visited terraces which had just been tilled and visually evaluated the stability of the topsoil aggregates using a 3-level scale (low/moderate/high) (Scheffer and Schachtschabel 1982, pp. 144-145). The second method was based on assessment, also visual, of the structural stability of "air-dried" clods when situated in 250cm^3 core samplers filled with water (cf. Sekera 1959, pp. 8-9; Bergsma 1985, p. 13).

With the help of these two very simple methods, it was possible to quickly assess the aggregate stability of the soils both when exposed to impacting rain and when submerged in water. This evaluation was facilitated by the circumstance that the degree of damage was generally high and on the whole varied very little. For example, it turned out that the loosening effect of tilling the soil with a hook plow is only of short duration, since the mechanically loosened soil aggregates are unable to resist even light rain for long, and their surfaces are sealed off (see Photograph 6). The same phenomenon was observed in the core sampler tests. As soon as the water had completely infiltrated, the clods within the core sampler disintegrated into a glaze-like, impermeable layer (cf. Photograph 6).

As a rule, the total thickness of the sealing layer or skin caused by impacting raindrops or immersion in water was between 0.5 and 1 cm (see Photograph 7). It consisted of thin, plate-like, horizontally aligned strata with an approx. thickness of 1 mm each, which apparently owe their formation to silt particles being suspended in a thin film of standing or flowing water on the surface and then being deposited on the soil surface by settling action or as a result of infiltration or evaporation (cf. Bryan 1977, pp. 67-68; Breburda 1983,

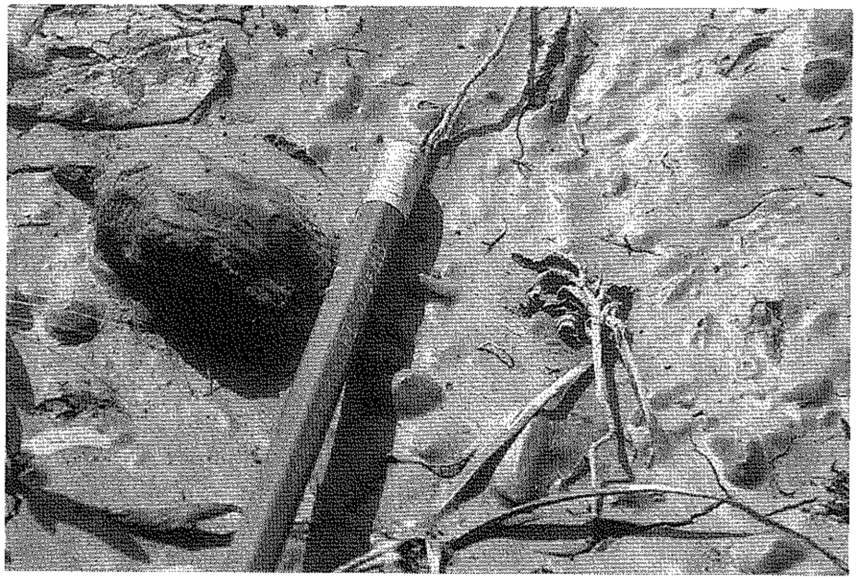
p. 43). When they begin to dry out, these surface layers of fine sediment bake into crusts exhibiting characteristic polygonal cracks. M. SINGER and I. SHAINBERG (1988) designate such surface crusts formed by structural disintegration (microerosion) (Sekera 1951; 1959) as structural crusts.

The low stability of the aggregate structure created by tilling with the hook plow is a direct result of the particle size distribution of the soils (low in clay, high in silt) and their low humus content (cf. Morgan 1979, p. 22; Jung and Brechtel 1980, p. 107; Arbeitsgruppe Bodenkunde 1982, p. 193, King et al. 1983, p. 144). While stable aggregates predominate in clayey, humus-rich soils, which are formed by the combination of clay minerals with humic substances (organomineral complexes), soils with high proportions of silt and very fine sand - like those in the study area (see Table 9) - possess only low aggregate stability. Due to the low surface forces of the soil particles, the aggregates break down even before they are fully saturated with water (Gehrenkemper 1981, p. 49; Arbeitsgruppe Bodenkunde 1982, p. 193). Sorption of sodium ions is not likely to play any significant role in connection with the low aggregate stability of the studied soils (see pH-value, $CaCO_3$ content), since the destabilizing effect of such ions does not gradually make itself noticeable until the Na-saturation of the exchange body exceeds 2% (Singer and Shainberg 1985; cf. Arbeitsgruppe Bodenkunde 1982, p. 192; Scheffer and Schachtschabel 1982, pp. 108 and 226-227).

Nor is the low texture-related stability of the soil aggregates when exposed to water improved in the study area by cementation of the primary particles with humus. By Central European standards, the topsoils of the investigated terrace profiles are very low (0.5-1%) to low (1-2%) in humus content, reaching moderate levels only on a few grass-covered sites (2-3%) (see Table 3; cf. Kuntze et al. 1981, p. 123; Scheffer and Schachtschabel 1982, p. 48). In order to permit greater humus formation in these soils, more organic material would have to be present, as well as an intact community of soil microorganisms. The fundamental importance of soil microorganisms for stabilization of soil aggregates results, on the one hand, from the binding action of colonies of bacteria, threads of organisms and microbial gum, and on the other hand from breakdown (fermentation) of the decomposable biomass with subsequent humification. The ulmin produced serves to additionally cement the existing soil structure and impart a stabilizing lining to the pore spaces (Sekera 1959, pp. 16-17; cf. Lugo-López and Juárez 1959, p. 271; Klaer and Krieter 1982, pp. 156-158). Instead of continuously adding fresh organic material in order to enhance aggregate stability and improve the soil structure, the Yemeni farmers use all of the crop residues as animal fodder and fuel. As a result, there is virtually no production of litter (Kopp 1981, p. 116). The organic material which remains is sufficient only for formation of a slightly humic topsoil, the humus of which is then rapidly broken down again as a result of the frequent mechanical tilling (Alkämper et al. 1979, p. 30).

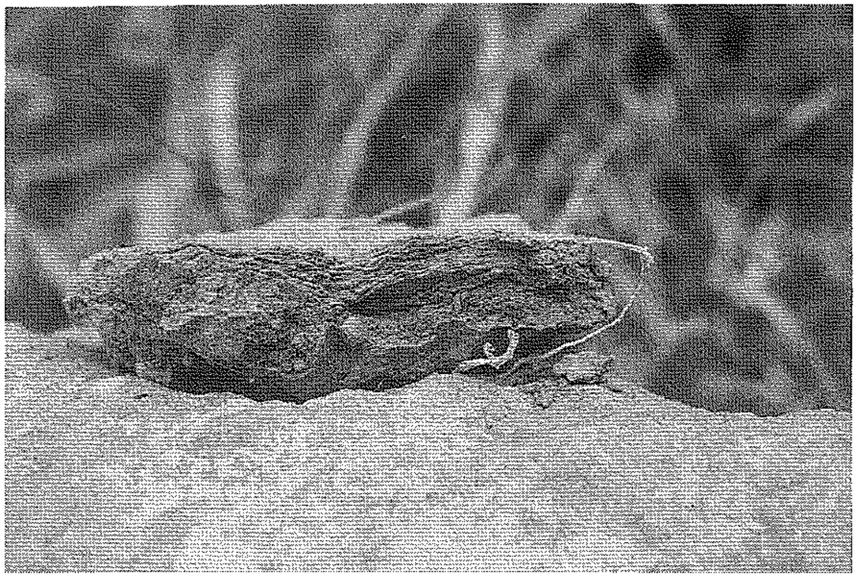
As a result, the soils are constantly subjected to sealing and crust formation (see Photographs 6 and 7). These structural crusts, which must be loosened over and over again by strenuous and time-consuming work with the hoe or hook plow, prevent rapid infiltration of rainwater and irrigation water, thus causing unnecessary evaporation losses and reducing yields. During very heavy rains they definitely cause erosive surface runoff even on farmed terraces.

Photo 6: Surface sealing on a mechanically tilled terrace soil (Jabal Shibam)



H. Vogel (9/19/84)

Photo 7: Fresh soil fragment with structural crust (on a terrace below the Ashami field). Scale: 1:0.9



H. Vogel (9/29/84)

The depositional crusts (Singer and Shainberg 1988) which can be frequently observed on abandoned terraces in the initial stages of destruction are identical in appearance and in their effects to structural crusts, but owe their formation to a completely different process. They arise as a result of colluvial covering (sealing-over) of still (virtually) intact terraces with soil material washed down from higher terraces in which intense erosional processes are active. Some of the affected terraces are already covered by a thick deposit of sediment reaching to the top of the retaining wall which has an extremely high silt content, at least at the surface (0-5 cm) (see Table 11 - T 3/4). In the case of such depositional crusts, the superficial, also horizontally aligned, sealing layers are up to 3-5 cm thick. In contrast to structural crusts formed by impacting raindrops or wetting by immersion, these depositional crusts owe their formation to deposition of suspended sediments carried in by floodwaters that are trapped and pooled; the relatively large, light silt particles are then the last to settle (cf. Singer and Shainberg 1988).

The formation of structural and depositional crusts likely results in a fundamental modification of the dynamics of soil erosion, since then discrete soil aggregates are no longer exposed to "attack" by falling raindrops, and virtually no loose soil is present that can be entrained and carried away by (shallow) sheet flow.

Various studies have shown that the intensity of soil loss from freshly tilled fields caused by splash or sheet erosion is considerably higher than on fields that have already been sealed by water action (Woodruff 1947, p. 475; McIntyre 1958a, pp. 262-265; Jung and Brechtel 1980, p. 97). As long as the fine soil material remains embedded in the sealing layer or crust, it cannot be dislodged and removed. At least on farmed terraces, the sheet erosion which becomes active when runoff washes across them is rapidly neutralized by development of sealing layers. In the case of abandoned terraces, however, because of the certainly drastically increased runoff rates it must be assumed that, on the one hand, the existing structural and depositional crusts will be repeatedly broken apart while, on the other hand, gully erosion is significantly intensified (cf. Sekera 1959, pp. 22-23; Stocking and Elwell 1976, p. 11; TU Berlin 1980, p. 111).

From this it is apparent that aggregate stability as a measure of the erodibility of a particular soil can usually only be meaningfully applied to agriculturally utilized soils, on the surface of which freshly tilled clods are directly subjected to the action of water. In the case of non-aggregated soils, however, or such that are characterized by structural or depositional crusts, this index loses its value. In this case, soil erodibility is determined not by the stability of individual aggregates, but instead by the soil mass as a whole, i.e. by the shear strength of the soil, which is in turn dependent on internal friction among the soil particles, the cohesive forces acting between them, and water pressure in the soil pores (Bryan 1977, pp. 69-70).

bb) The permeability of terrace surfaces

Within the scope of the field studies, a total of 14 permeability test series were conducted on terrace surfaces using the field method by H. RID (1984, pp. 114-115).

In this simple method, core samplers - in the present case with a volume of 250 cm^3 - are driven halfway into the soil layer being tested, and the other half filled with water. The time required for the water to infiltrate into the soil is then used to determine permeability. The values thus obtained were assigned to permeability classes on the basis of the threshold values for infiltration rates (see Table 5) proposed by M. HOLY (1980, p. 113) for the Wischmeier nomograph (see Fig. 15). For purposes of comparison, the average permeabilities of different soil types as a function of texture and effective soil density were also determined (see Table 5, Arbeitsgruppe Bodenkunde 1982, p. 152; cf. Schwertmann 1981, p. 13). Effective soil density was calculated on the basis of bulk density (Kuntze et al. 1981, p. 195; Arbeitsgruppe Bodenkunde 1982, p. 128).

Table 5: Permeability classes.

Class	Description	Infiltration rate in cm/h	
		HOLY-WISCHMEIER	ARBEITSGRUPPE BODENKUNDE
1	very slow	< 0.1	> 0.04
2	slow	0.1 - 0.5	0.04 - 0.42
3	moderate	0.5 - 2.0	0.42 - 1.70
4	fast	2.0 - 6.0	1.70 - 4.20
5	very fast	6.0 - 12.0	4.20 - 12.50
6	extremely fast	> 12	> 12.5

Source: Holy (1980, p. 113); Arbeitsgruppe Bodenkunde (1982, p. 153)

The aim of these permeability measurements was to obtain an approximate idea of the relative frequency and probability of occurrence of surface runoff on abandoned terraces with different surface textures, as well as on farmed terraces. For this purpose, four test series of 2 to 4 test runs each were conducted, each involving the placement of 6 core samplers on freshly loosened terraces and ten on abandoned terraces. Per test run and core sampler, 125 cm^3 of water was allowed to infiltrate on a surface area of 50 cm^2, i.e. the cumulative infiltration was 2.5 cm. The core samplers were filled, after being driven into the soil, with water poured from a water bottle, without attempting to prevent (additional) splashing of water onto the soil surface, since it was also impossible to prevent loosening of the soil when driving the core samplers. To be sure, the core samplers were moved over and driven in again if the resulting loosening of the soil was excessive - which frequently occurred in the case of very stoney soils or when breaking up structural or depositional crusts - but no matter how carefully the core samplers were driven in, it was never possible to completely prevent the loosening effect. The core samplers were shielded from direct sunlight by rocks (see Photograph 8).

Photo 8: Measurement of permeability on a terrace field.

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As indicated by the threshold values listed in Table 5 and determined using the field method by H. RID (1984), the dry loam and silt soils of abandoned terraces possess moderate to high, in unfavorable cases only low water permeability (see Table 8). In the case of terrace surfaces which have merely been sealed over by water action, the average infiltration rates were between 5.8 cm/h in the first test run and 4.2 cm/h in the second (see Table 6). In the case of terrace surfaces with colluvial deposits, the average infiltration rate dropped off again significantly to 3.3 cm/h in the first test run and 1.9 cm/h in the second (see Table 6). Particularly serious conditions were observed on depositional crusts completely lacking in course fragments. For instance, in one test on the Ashami field it took nearly 7 hours for all of the water to infiltrate. The infiltration rate was thus as low as 0.3 cm/h (this value was not included when calculating the average for Table 6), corresponding to very low permeability.

Without a doubt, a major role was played by the particle size distribution (texture) of the soil (cf. Pagel and Al Murab 1966, p. 275). Where the tests were conducted on the Ashami field, the fine to coarse sand fraction accounted for only 1.5%, coarser fragments being entirely absent; by contrast, at another terrace site also largely covered by deposits (T4) there was between 5 and 15% of fine to coarse sand and 20% of course fragments, the silt (70-80%) and clay fractions (10-15%) being the same. In this case permeability was moderate to high instead of moderate to low (see Table 8).

The significantly higher infiltration rates exhibited by stony surface horizons are a visible expression of the larger pores and water drainage channels created by the coarse fragments in the soil, as a result of which permeability is considerably improved, particularly in the sandy soils of the study area which have a high proportion of course fragments (cf. McIntyre 1958b, p. 189; Klaer and Krieter 1982, p. 159). However, since the infiltration rates measured using the field method described above were distorted somewhat by the unavoidable loosening of the surface soil or breaking up of surface crusts, they are definitely (somewhat) too high (cf. McIntyre 1958b, p. 187).

Considerably better conditions prevail on farmed sites which have not yet been sealed by water action, as compared with the terraces that have been sealed or covered by depositional layers. Mechanical loosening of the upper 20 to 25 cm results in significantly increased infiltration rates, expressing itself as an average value of 11.5 cm/h for the first test run. The unstable soil aggregates were disintegrated by the water during the first test run, however, resulting in a much lower average infiltration rate in the second test run (6.3 cm/h) (see Table 6). Here too, like in the case of the depositional crusts, extreme values can occur which deviate significantly from the average. For example, on a freshly tilled terrace below the Ashami field relatively high initial water infiltration rates of between 30 and 40 cm/h were measured, corresponding to a permeability rating of 6-5 (see Table 7). These values provide a vivid illustration of the great importance of regularly loosening the soil prior to rainstorms.

Table 6: Average infiltration capacities on farmed and abandoned terraces.

Use	Soil class	Average infiltration time in minutes		Average infiltration rates in cm/h	
		1st	2nd	1st	2nd
		test run		test run	
Farmed terraces (freshly tilled)	sandy loam/ loam	13.0	24.0	11.5	6.3
Abandoned terraces	sandy loam/ loamy sand	26.0	36.0	5.8	4.2
Abandoned terraces	silt loam/ sandy loam	46.0	79.0	3.3	1.9

Table 7: Permeability of unsaturated top soils.

No.	Soil class	Permeability acc. to RID and HOLY - WISCHMEIER (unsaturated)		Permeability acc. to ARBEITSGRUPPE BODENKUNDE
		Initial	Final	
		test run		
I.	sandy loam*	5 - 4	4	4
II.	loam*	6 - 5	5 - 4	5
III.	sandy loam*	6	5 - 4	4
IV.	silt clay loam*	4 - 3	3	3

* Pinch test

As can be seen, on the whole it emerged that the permeability of mechanically tilled soils is high, so that, because of the basin method of irrigation used, rainwater and irrigation water can be largely absorbed by the generally "dry" soils. In the case of very heavy high-intensity rains, however, the sealing of the soil surface caused by the low aggregate stability most certainly leads to frequent or perhaps even regular overflow of the terraces.

On abandoned but still intact sites, because of the existing structural and depositional crusts and the common erosion pavements (Riquier 1978, p. 56), erosive surface runoff definitely occurs even in connection with precipitation events with only a few mm of rainfall (cf. Eger 1984, p. 155). As soon as the raised crest of the retaining wall is damaged or an erosion gully has formed, the water infiltration capacity of the soil surface becomes secondary in importance. If it is impossible for standing water to accumulate on the terraces, and if the water is guided into defined runoff channels, then - within the context of the prevailing precipitation structures and plant cover - slope steepness asserts itself as by far the most important factor influencing erosion. This holds true even where significantly improved conditions for infiltration exist, e.g. on farmed terraces, since the water has no time to infiltrate.

If those soil attributes with an important bearing on soil permeability in the study area are summarized in order of their significance, the following picture emerges:

1. Formation of structural crusts parallel to the soil surface as a result of the low stability of the soil aggregates under the influence of falling rain and immersion in water (inhibiting permeability).
2. Formation of depositional crusts as a result of colluvial sedimentation (inhibiting permeability).
3. Entrapment of air in the soil ("air cushions") in the course of alternate moistening and drying of the soil (inhibiting permeability).
4. Formation of clay-enriched horizons (inhibiting permeability).

a) Loosening of the topsoil by hook plow[6] and hoe (promoting permeability).

b) High proportion of course fragments in the soil (promoting permeability).

c) Formation of cracks when the soil dries (promoting permeability).

To conclude, I would like to stress once again that the infiltration rates measured with the aid of the field method by H. RID (1984) are not intended as an absolute measure of the water infiltration capacity of the investigated surface horizons, since on the one hand this simple method definitely does

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[6] According to G. KITTLER (1963), the terms hook and plow should never be used together when considering agromorphological aspects.

Table 8: Permeability (Pb) and erodibility (Eb) classes of selected surface horizons (0-5 cm) on abandoned terraces.

No.	Texture	Coarse fragments % vol.	Bulk density	Effective bulk density	Soil moisture	Pb^1 acc. to RID and HOLY - WISCHMEIER Inital test run	Pb^1 acc. to RID and HOLY - WISCHMEIER Final test run	Pb^2 acc. to ARBEITS-GRUPPE BODEN-KUNDE	Soil aggregate class	K-factor 1st approximation	K-factor value	Eb	Coverage by coarse fragments	Adjusted K factor	Eb
T 1	loam	15	1.29	1.43	4.62	4 - 3	3	4 - 3	3	0.48	0.55	4	50	0.16	2
	silt loam	30	1.34	1.44	3.22	4 - 3	3	3	3 - 4	0.47	0.56	4		0.16	
T 2	clay loam	15	1.42	1.50	2.70	4	4	3	3 - 4	0.61	0.67	4	15	0.46	3
a	silt loam	20	1.39	1.45	3.60	4	4 - 3	3	3 - 4	0.68	0.75	4		0.52	4
b	sandy loam	15	1.49	1.54	2.24	5 - 4	4	3	3 - 4	0.53	0.58	4	15	0.40	3
	silt loam	15	1.38	1.45	2.70	4	4 - 3	3	3 - 4	0.67	0.75	4		0.52	4
T 3	silt loam	0	1.20	1.31	3.28	3 - 2	3 - 2	4	4	0.66	0.78	5	0	-	5
	silt loam	0	1.13	1.22	1.99	3	3 - 2	4	4	0.68	0.81	5			
T 4	silt loam	20	1.16	1.26	6.50	4	4	4	4	0.68	0.76	5	5	0.68	4
	silt loam	20	1.08	1.19	5.10	4 - 3	4 - 3	4	4	0.68	0.77	5		0.68	
T 5	loamy sand	40	1.48	1.55	1.90	5 - 4	4	4	3	0.57	0.61	4	45	0.21	2
	sandy loam	40	1.56	1.63	2.20	4	4	3	3	0.58	0.61	4		0.21	
T 6	loamy sand	40	1.49	1.59	1.83	6 - 5	4 - 5	4	3	0.43	0.45	3	75	0.06	1
	loamy sand	40	1.53	1.64	2.50	5 - 4	4	4	3	0.46	0.50	3		0.07	
T 7	sandy loam	30	1.32	1.47	3.15	5	4 - 5	4	3	0.45	0.47	3	35	0.20	2
	silt loam	30	1.39	1.51	2.41	5 - 4	4	3	3	0.58	0.62	4		0.27	3
T 8	silt loam	15	1.20	1.34	3.22	4	4 - 3	4	4	0.51	0.61	4	25	0.33	3
	loam	30	1.32	1.51	3.81	4	4	4 - 3	3	0.38	0.42	3		0.23	2

1) unsaturated (or partially saturated)
2) saturated

not yield results anywhere near as accurate as those obtained using a double-ring infiltrometer, and on the other hand the loosening of the soil caused when driving the core samplers into abandoned terraces definitely led to shortened infiltration times.

In spite of this considerable handicap, however, it was nevertheless possible to identify the most important differences between the various sites.

bc) Nomographic determination of K-factor values

As already discussed above in connection with aggregate stability, soil attributes - in addition to climate and relief - play a central role as indicators of the inherent natural risk of erosion, since these determine how much soil material can be eroded by impacting rain and surface runoff (cf. Chapter II, section 1). The physical attributes of the (surface) soil are most important, but the chemical attributes are also significant. The susceptibility of a given soil to erosion by the forces acting upon it, i.e. soil erodibility, is a function of the detachability of the soil particles when hit by impacting raindrops (splash) on the one hand, and on the other hand of their resistance to entrainment and lateral displacement (transportability) by water flowing on the ground surface (Hudson 1977, p. 175; cf. Chapter II, section 3 a-c).

As shown by the extensive studies conducted by W. WISCHMEIER et al. (1971) and W. WISCHMEIER and D. SMITH (1978), the erodibility of a particular soil when acted upon by flowing water is primarily determined by five soil attributes, namely particle size distribution (texture), the humic content of the topsoil, i.e. the plow layer, the size of the surface aggregates (soil structure), and the permeability to water of the soil profile. These soil attributes are quantified in the form of the K factor of the Universal Soil Loss Equation, which ranges from 0.0 (non-erodible) to 1.0 (very high erodibility) (cf. Fig. 15). This provides a measure of long-term average soil loss (t/ha) per rainfall erosivity unit (EI), i.e. per unit of the rainfall and runoff factor R, and can be experimentally determined on standardized test plots on the basis of the following relation (Wischmeier and Smith 1978, p.8; cf. Chapter II, section 2; Lenthe et al. 1981, pp. 33-34; Hudson 1981, p. 194):

$$K = \frac{A}{R}$$

Since such soil loss measurements are very cost-intensive and time-consuming, besides being impracticable within the scope of short-term studies like this one, W. WISCHMEIER et al. (1971) developed a nomograph with the aid of which the K factor can be approximately determined if soil analysis data are available (cf. Fig. 15; Wischmeier and Smith 1978, pp. 9-11; Arbeitsgruppe Bodenkunde 1982, pp. 301-302). Particle size and carbon content analyses are of overriding importance here, since the erodibility of a particular soil is primarily determined by its texture, followed by its content of organic matter (humus). Together, these two soil attributes yield a first approximation of K, which is sufficient for practical purposes provided that the surface aggregates of the soil in question are only 1-2 mm in diameter (fine granular) and the water infiltration capacity of the soil is moderate. For all other soil types, the right half of the nomograph must also be taken into account (Wischmeier et al. 1971, p.191; Wischmeier and Smith 1978, p. 10).

The five main soil attributes incorporated into the nomograph are used for determination of the K factor in the following way:

1. Particle size distribution (soil texture)

a) A high proportion of silt and very fine sand (2-125 µm in diameter) has the effect of promoting erosion, since these two particle size fractions are particularly susceptible to sealing (low aggregate stability) and are most readily washed away (Wischmeier et al. 1971, p. 190; Wischmeier and Smith 1978, pp. 9.10; cf. Jung 1965, p. 58; Arbeitsgruppe Bodenkunde 1982, p. 193; Schwertmann 1982, p. 11).

b) A high proportion of fine to coarse sand (0.125-2 mm in diameter) has the effect of inhibiting erosion, provided that the percentage of silt and very fine particles (not including the clay fraction) is less as a result, i.e. the relative percentages of the three fine soil particle types are important, since soils whose texture is excessively one-sided are more likely to be eroded than soils with a balanced distribution of all particle size groups (Wischmeier 1977a, p. 48; cf. G. Richter 1965, p. 197; Schwertmann 1977, p. 778; Breburda 1983, pp. 29-30).

2. A high content of organic matter has the effect of inhibiting erosion, since the presence of humus improves soil structure by facilitating the formation of stable aggregates, so that the soil becomes able to assimilate air and water. Soils with a humus content of less than 2-4% must be generally categorized as extremely susceptible to erosion (Kuron and Jung 1961, p. 140; Weitzenberg 1973, pp. 173-174; Morgan 1979, p. 22; Evans 1980, p. 120).

3. High permeability to water has the effect of inhibiting erosion, since a large to very large part of the rainfall volume can be absorbed by the soil, thus reducing runoff.

4. Coarse soil structure has the effect of promoting erosion, since the following general rule holds: "soil compactness increases with coarseness of the soil structure and decreasing porosity" (Arbeitsgruppe Bodenkunde 1982, p. 119). Compacted soils prevent rapid infiltration of rainwater, thus provoking erosive surface runoff.

   This makes it apparent that the K factor of the USLE implicitly reflects infiltration as determined by soil structure (Singer and Shainberg 1988).

Basically, K-factor values determined with the aid of the nomograph - instead of performing direct field measurements - represent an indirect but nevertheless quantitative physical measure of site erodibility. It must always be taken into account, however, that this factor only yields usable, i.e. reliable, values with respect to long-term average soil loss, but not for a single year or even a single rainfall event (Wischmeier 1977b, pp. 375-376).

Since the informational value of K-factor values determined with the aid of the nomograph - i.e. without performing long-term erosion measurements on standardized test plots - is limited as a quantitative measure of erodibility due to possible extrapolation errors (cf. Hudson 1977, p. 176), they have been applied here as a means of qualitatively assessing the susceptibility to erosion of terrace soils. For assessment purposes the erodibility classes defined by the ARBEITSGRUPPE BODENKUNDE (1982, p. 172) were used (see Fig. 15).

In addition to particle size and organic matter analysis, a system for designation of aggregate and permeability classes was also required, this was also borrowed from the ARBEITSGRUPPE BODENKUNDE (1982, pp. 119 and 152). In the case of the permeability classes, this was supplemented by field inspections of the overall profile (to a depth of 1 m) on the basis of soil texture and certain soil attributes (Kent Mitchell and Bubenzer 1980, p. 34; Hudson 1981, pp. 171-172). Since in the case of "air-dry" soils and a predominance of brief high-intensity rainfalls the influence of relatively impermeable subsoils does not make itself felt (Wischmeier et al. 1971, p. 191; cf. Singer and Shainberg 1985) the permeability classes identified for the various profile sections were not averaged (Schwertmann 1981, p. 15); instead, separate assignments were made for the topsoil and subsoil. The aggregate classes were determined in the field with the aid of a filar micrometer and graph paper with millimeter rulings.

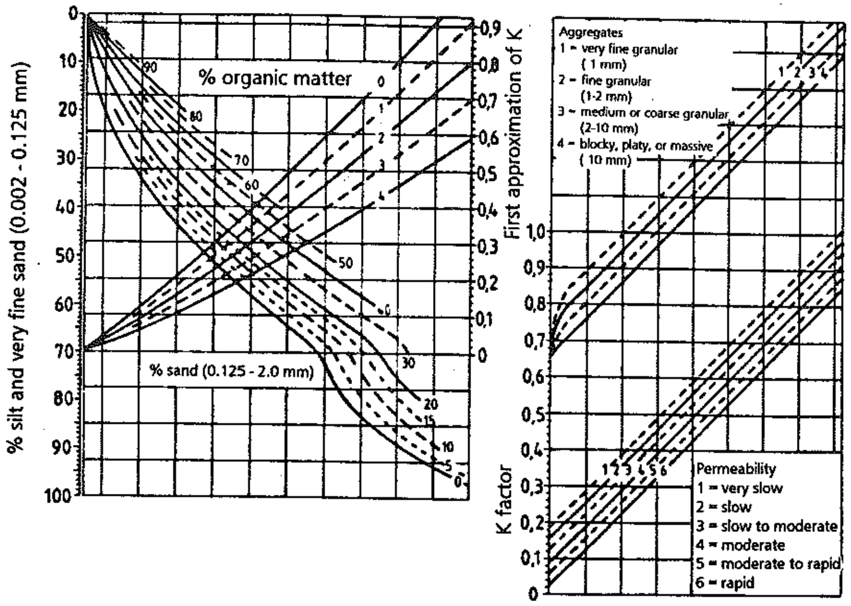
In view of the high intensity of soil erosion in the study area, in all cases the K factors of the subsoils (30-60 cm) were also determined (see Table 9).

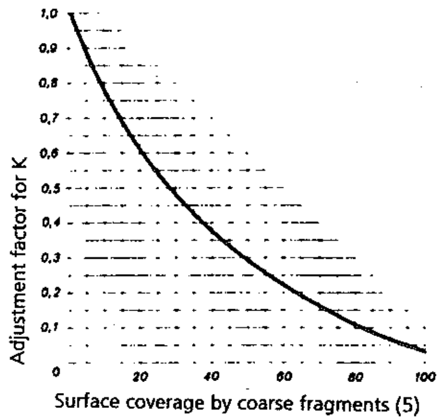
Although the nomograph for computing the soil erodibility factor K was originally developed on the basis of soil data on the loessal and morainal landscapes east of the Rocky Mountains (Schwertmann 1981, p. 20), it has since gained widespread use all over the world (cf. Morgan 1979, p. 52; Arbeitsgruppe Bodenkunde 1982, pp. 301-304). Application of the nomograph to soils outside of the United States is made easier by the fact that soil erodibility, according to the results obtained in the USA, is largely determined by soil attributes which are relatively simnple to determine and which are found in all specimens, above all soil texture (cf. Breburda 1983, p. 39). Nonetheless, later studies, e.g. in the African tropics as well as in the temperate latitudes of Central Europe, revealed that the soil loss rates obtained by experimental means on test plots, and estimated using the nomograph, varied considerably as a result of other soil attributes (e.g. soil structure), some of them significant (e.g. superficial silting, Fe and Al oxides) (cf. Nortcliff 1986, p. 250). Previous soil erosion studies had shown that the nomograph fails to precisely reflect the susceptibility to erosion of stony soils to sheet erosion, yielding a value which is too high, since the presence of coarse fragments on the surface (surface gravel) has an erosion-inhibiting effect similar to that of mulch (Wischmeier and Smith 1978, p. 10; cf. Kuron and Jung 1977, p. 139; Jung and Brechtel 1980, p. 86). The same conclusion was arrived at by E. ROOSE (1977, p. 65; 1980, p. 158), who tested the nomograph on soils in West Africa, obtaining thoroughly satisfactory results in all cases except stony and rock-covered soils.

Since a high proportion of coarse fragments is also characteristic of the terrace soils in the study area, the K-factor values determined in the course of this study were also corrected downwards by a factor proportional to the degree of coverage by large rock fragments (see Fig. 15; Wischmeier and Smith 1978, p. 19).

Tables 8 and 9 show that the erodibility of the terrace soils in the study area is generally classifiable as moderate to high and, where terraces are covered by colluvial deposits, even very high. The vertical differentiation of soil erodibility at specific sites is insignificant, a fact which is primarily due to the circumstance that the sediments from which the terrace soils have been built up usually do not exhibit any well-defined pedogenetic horizons. The uniform high erodibility of both the topsoil and the subsoil is vividly illustrated in the field by the deep U-shaped gullies.

Fig. 15: Nomograph for determining the soil-erodibility factor (K); adjustment nomograph; erodibility classes:





K factor acc. to WISCHMEIER and SMITH	Eb (erodibility) classes	
	Description	Symbol
≤ 0.10	very low	Eb 1
0.11 - 0.25	low	Eb 2
0.26 - 0.50	moderate	Eb 3
0.51 - 0.75	high	Eb 4
> 0.75	very high	Eb 5

Source: Arbeitsgruppe Bodenkunde (1982, pp. 302, 304 and 172)

In the long run, the erosion pavements formed by the impact of raindrops on the surfaces of abandoned terraces serve to protect the soil to a certain extent from sheet erosion, which in the case of the investigated (abandoned) terrace sites is expressed in the form of prevailing low to moderate erodibility as determined on the basis of the adjusted K factors (see Tables 8 and 9). However, due to the high-relief energy and prevailing precipitation conditions of the study area - with quickly swelling, very turbulent and frequently channeled surface runoff - this reduction is canceled out, a phenomenon which is dramatically illustrated by the high degree of damage to terrace complexes which have been left untended for long periods of time, resulting in them being completely leveled within just a few decades (cf. Chapter II, section 3c).

It is thus apparent that in an outer tropical mountain region like the Haraz, which is climatically characterized by brief but very erosive, high-intensity rainfall and long dry periods, slope steepness is the most important factor, soil erodibility playing only a comparatively subordinate role (cf. Späth 1976, p. 126; Arnoldus 1977, p. 42; Wischmeier and Smith 1978, p. 8).

To conclude, I would like to stress once again that, strictly speaking, the K factor only provides a reliable measure of the susceptibility of a specific soil to erosion by splash, sheet and rill erosion, leaving gully erosion out of account. To be sure, gully erosion is determined by the same factors (climate, soil, relief, vegetation and management), but the individual parameters and combinations of parameters governing these factors must always be separately identified and assessed for each type of erosional process (Hudson 1980, pp. 280 and 282; cf. Chapter II, section 3a-c).

c) Relief energy and slope steepness

Accurate prognosis of the intensity of soil erosion can only be made on the basis of detailed knowledge of the individual energy parameters. In the present case, it is most important to have available a characterization of the relief, since the emergence, type and erosive energy of runoff in the study area are primarily determined by various relief-related parameters (steepness, site placement with respect to the surrounding relief, slope topography, etc.) (cf. Chapter II, sections 3c and 4).

In general, mountain ecosystems like that of the Haraz area exhibit a higher inherent natural instability than the geoecosystems of lowlands. The principal reason for this is the higher *relief energy* of mountainous areas, the consequence of a material imbalance built up by endogenous forces (fault

Table 9: Erodibility classes (Eb) of selected soils.

No.	Profile depth cm	Clay 0.002 mm	Silt 0.002-0.06mm	Very fine sand 0.06-0.125mm	Fine to coarse fragments 0.125-2 mm	Effective bulk density g/cm³	Permeability	Soil aggregate class	K factor		Eb	Coverage with coarse fragments	adjusted K factor	Eb
				in % of fine soil					1st approximation	value				
P 1	0 - 30	12.83	29.54	16.03	41.60	1.45	4	3	0.39	0.44	3	40	0.17	2
	30 - 60	13.09	31.99	14.04	40.87	1.47	4	3	0.40	0.45	3	-	-	-
P 2	0 - 30	21.65	42.10	7.14	29.12	1.53	4 - 3	3	0.36	0.42	3	50	0.12	2
	30 - 60	21.72	41.16	7.47	29.65	1.40	4 - 3	3	0.36	0.42	3	-	-	-
P 3	0 - 30	9.14	46.04	14.66	30.17	1.48	3	4	0.62	0.72	4	15	0.50	3
	30 - 60	13.24	40.84	12.31	33.61	1.54	3	4	0.52	0.62	4	-	-	-
P 4	0 - 35	7.39	30.21	11.84	50.56	1.42	3	4	0.34	0.46	3	50	0.13	2
P 5	0 - 30	10.84	41.05	8.98	39.13	1.48	3	3 - 4	0.45	0.54	4	50	0.16	2
	30 - 60	12.35	30.83	8.39	48.43	1.56	4	3 - 4	0.38	0.43	3	-	-	-
P 6	0 - 30	12.43	37.16	10.38	40.04	1.49	4	3	0.41	0.45	3	40	0.17	2
	30 - 60	13.99	44.75	9.17	32.09	1.46	3	3	0.48	0.55	4	-	-	-
P 7	0 - 30	7.83	48.79	15.09	28.28	1.38	4	3	0.52	0.56	4	50	0.16	2
	30 - 60	10.62	48.31	12.87	28.20	1.40	3	3	0.55	0.62	4	-	-	-
P 8	0 - 30	12.09	44.66	11.84	31.41	1.41	3	4	0.54	0.64	4	30	0.31	3
	30 - 60	12.50	48.92	9.35	29.22	1.51	3	4	0.51	0.62	4	-	-	-
P 9	0 - 30	12.48	44.39	8.45	34.67	1.51	3	3 - 4	0.39	0.48	3	50	0.14	2
	30 - 60	13.88	41.70	9.32	35.10	1.52	3	4	0.45	0.56	4	-	-	-
P 10	0 - 30	23.10	47.41	7.78	21.70	1.48	4 - 3	4	0.44	0.54	4	50	0.16	2
	30 - 60	28.66	42.73	7.06	21.55	1.69	3	4	0.40	0.52	4	-	-	-
P 11	0 - 30	20.89	41.37	9.17	28.57	1.57	4 - 3	4	0.40	0.50	3	25	0.28	3
	30 - 60	34.28	37.44	6.86	21.43	1.90	2 - 1	4	0.33	0.50	3	-	-	-

tectonics, fissural volcanism) and exogenous forces (water erosion) (Schwertmann 1977, p. 711; Kienholz et al. 1982, p. 36). In outer tropical mountain regions like the Haraz, the threat to the landscape posed by the relief energy is particularly high, since the geomorphodynamic processes involved in wearing down the mountains are intensified and accelerated by unfavorable climatic conditions. As has already been shown, this climatic zone is characterized by dry seasons of long duration in which the vegetation stops growing, alternating with rainy seasons that often begin abruptly and with great intensity (see Chapter III, section 2, and Chapter IV, section 2 a). While the rainfall energy thus released is exponentially increased by the high relief energy, once surface runoff develops, the sparse vegetation - at least at the beginning - is as a rule unable to perform its stabilizing function, even under natural conditions.

However, the fundamental significance of the relief is expressed not solely in the energy which it imparts to the dynamics of soil erosion, but also, for example, by differences in the degree of exposure of terrain (e.g. rain shadows), accumulation of water on concave slopes, or the influence exerted on the "critical duration of rainfall" (Strele 1950, p. 18), i.e. the time which elapses between the onset of rain and the beginning of runoff. Besides the soil attributes already discussed (see Chapter IV, section 2 ba), the vegetation and the rainfall intensity, the critical duration of rainfall is also dependent on the size of the catchment area and therefore on the relief (cf. Chapter III, section 4a). "All other conditions being equal, it increases with the size of the catchment area" (Strele 1950, p. 18). Since catchment areas decrease in size with greater relief ruggedness (steepness) (Breburda 1983, p. 47), the critical duration of rainfall is shortest in mountainous areas with a high relief energy. The material-laden flash floods so characteristic of outer tropical mountain ranges are therefore a dramatic expression of the relief when exposed to heavy rain (Scoging 1980, p. 349).

The above discussion makes it clear that the influence of relief on water erosion is mainly related to the relief energy. Relief energy as a measure of the relative differences in height between relief elements which belong together morphologically (e.g. mountain top/valley floor) or between the highest and lowest relief points within an artificially delimited area (1 km^2), however, can only be meaningfully applied for geomorphographical classification of the large-scale relief (relief type) and the individual forms in which this is manifested, but not for direct assessment of the risk of erosion on a given slope or individual site (Kugler 1977, p. 190). The danger of erosion on a specific site can be best determined by its (mean) *slope* *steepness*, which reflects the relief energy on a surface area of any desired smallness (G. Richter 1965, pp. 231-234; Stocking 1972, pp. 439-442; Hudson 1981, pp. 84-85; Briggs and France 1982, p. 222).

For this reason, for this study the decision was made to dispense with a cartographic representation of the relief energy as a measure of the differences in height between the highest and lowest relief points of a natural or artificial surface unit, and instead to depict it in the form of a slope steepness map (see Slope Steepness Map). In addition, the relief energy of each square kilometer of the study area was identified and classified using the system by H. KUGLER (1976, p. 201), and subsequently represented in tabular form (see Table 10).

Table 10: Relief energy in the study area.

Relief energy class	Mountain relief 1	Mountain relief 2	Mountain relief 3
Relief energy	101 - 200 m/km^2	201 - 500 m/km^2	501 - 1000 m/km^2
Proportion of total surface area			
km^2	6	27	16
%	12	55	33

For preparation of the slope steepness map, which is also based on the slope steepness classification scheme developed by H. KUGLER (1969, p. 247), a gradiometer was made following the instructions of the ARBEITSGRUPPE BODENKUNDE (1982, pp. 309-312). With the aid of this device, the 40-m contour lines on the topographical map of the study area (enlarged to a scale of 1:10 000) were evaluated, and the slope steepness groups dominating in terms of surface area were mapped (cf. Kugler 1976, p. 202; 1977, pp. 190-191). In order to achieve the highest possible degree of agreement with the actual gradient values, generalizations were kept to a minimum; since only four standard groups were used for classification, this caused no major difficulties. During the course of my stay in former North Yemen, I checked the rough draft of the map at around 60 sites by measurements with an inclinometer.

With only a few exceptions, the slope gradients indicated in the slope steepness map are identical with the actual slope conditions. The cases in which these are deviated from were motivated less by having generalized the topography, than by the fact that the 40-m contour lines on the topographical map used as a basis were too far apart to always faithfully reflect the actual relief.

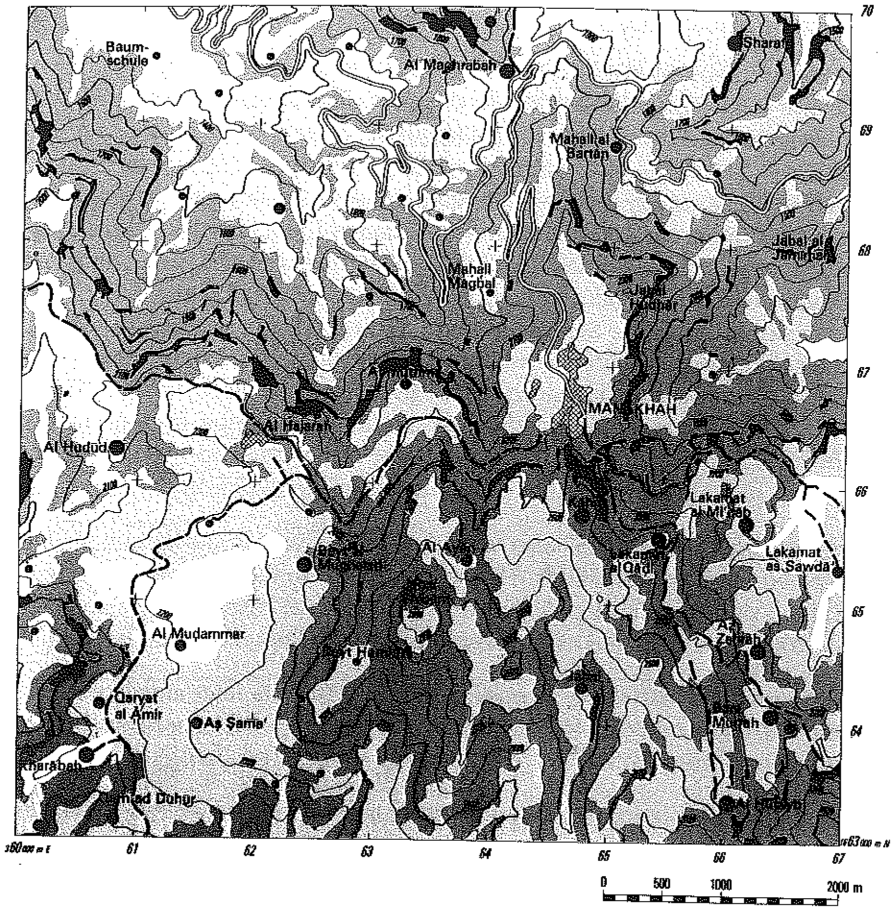
The slope steepness classification scheme by H. KUGLER (1969) was chosen because the threshold values of the different slope steepness groups which are distinguished reveal a great deal about the relief-related dynamics of soil erosion. Accordingly, the mapped medium and steep slopes which cover nearly the entire study area (see Slope Steepness Map) are also the sites with the highest inherent risk of erosion (see Chpater II, section 4), and can only be utilized agriculturally at all by constructing terraces and devoting great attention to keeping them in a good state of repair. The lower limit of the gentle slopes (cf. Slope Steepness Map) also represents a critical threshold, since soil removal by surficial water erosion begins at a minimum slope of 1 on agricultural soils with a particularly high index of erodibility (Kugler 1976, p. 192; cf. Zachar 1982, p. 286). As a number of slope measurements showed, such a minimum gradient can frequently develop even on intact terraces, requiring the farmers to carry out leveling work from time to time.

The threshold value of 25° also turned out to be very important under the observed land-use conditions. The reason is that in the study area terraces on steep slopes are now only farmed in exceptional cases. A slope angle of 35° (70%) was identified as the absolute (former) limit of terrace farming.

The fourth and last slope steepness group highlights lava and ignimbrite scarps 40 m or more in height, while the plateau-like areas are included in the zones of medium slope.

In summary, the predominantly very to extremely high relief energy in the study area - both on a large scale (see Table 10) and locally (see Slope Steepness Map) - characterizes it as a region with a maximum latent risk of water erosion, thus indirectly stressing the high impact and intensity of ongoing geomorphological processes (cf. Chapter II, sections 3 c and 4).

Slope Steepness Map



MANĀKHAH
Haraz Mountains

Slope type	Gradient	
Gentle slope:	1° - 7°	☐
Medium slope:	8° - 25°	▨
Steep slope:	26° - 60°	▩
Scarp:	61° - 90°	■

═══ Paved road

---- Unpaved road

Design and artwork: H. Vogel (1985)

3. The impact of changes in land-use patterns

In large parts of the study area, the massive emigration of workers to other countries and the shift of population to urban centers has led to a lack of manpower in the agricultural sector and consequently to complete abandonment of terrace farming. Because of the high natural risk of erosion discussed in the previous chapters, in the long run all of the abandoned, untended terraces are threatened by complete destruction.

In order to permit assessment and identification of the order of magnitude and spatial extent of the current soil erosion hazard, land use was also mapped within the scope of collection of basic data; relief and terrace features were studied, including the forms of soil erosion and degree of damage at selected sites.

Like the slope steepness map, the land-use map was also done on a scale of 1:10,000. The surveys for it were conducted between September 30 and November 7, 1984. The following land-use types were distinguished:

1. Farmed terraces

-	Annual crops	(grain)
-	Perennial crops	(coffee, qat)
-	Mixed cropping	(annual and perennial crops)

2. Other uses

-	Abandoned terraces	(used as pasture)
-	Pasture land	(slopes which have never been terraced)
-	Wasteland	(rocky areas partially used as pasture)

Prior to departing for former North Yemen, I had prepared a form for the purpose of carrying out the special site studies; minor aspects of it were then modified after arrival (see Appendix). The focus of the site studies was on a semiqualitative survey of predominant soil erosion forms and the degree to which the terraces had been damaged. Surficial and distinctly channeled types of soil erosion were considered, i.e. pluvial and gully erosion. Pluvial erosion was further broken down into splash, sheet and rill erosion. Splash erosion was assessed on the basis of erosion pavements and erosion pedestals. For determination of sheet erosion, flow lines with a maximum depth of 1 cm were considered which were clearly recognizable as channels of sealing action or fine sediment transport, or simply blades of grass which had been consistently bent in a uniform direction (see Photograph 14). If these fine-lined flow structures had already reached a depth of between 1 and 5 cm, then they were treated as rill erosion. With further incision and obvious concentration of runoff in these channels, a distinction was made between incipient (5-30 cm deep), minor (30-100 cm deep) and major (> 1 m deep) erosion gullies.

The extent of damage to the terraces was evaluated using a modified form of the classification criteria developed by F. FASSBENDER (1982; 1983) for the Haraz project (see Appendix). The site surveys were performed by studying selected plots of irregular size belonging to the same slope steepness and land-use groups. In addition, attention was paid to ensuring that the soils were derived from the same parent rock. On each of these plots, the erosional forms currently active and the extent of damage to the terraces were evaluated and the dominant and second-most-common forms of erosion identified, as were the dominant and second-most-common site classes. In addition, the type of erosion with the greatest intensity and the poorest site class were identified. This part of the data collection activities was carried out using a mapping method borrowed from J. SCHWING and H. VOGT (1980). The intentional distinction between erosional types on the one hand and degree of damage on the other was made because the visual damage (erosive forms) alone was generally insufficient to permit conclusive statements on the extent of damage to a given site (cf. G. Richter 1965, pp. 57 and 220-221). While, due to the lack of a thick layer of soil, only small and very small gullies were able to develop on totally destroyed terrace sites, the good and very good sites were often characterized by large gullies.

In the final analysis, the value of this evaluation scheme is due to the fact that it permits a clear perception of both the actual dynamics and intensity of the current soil-erosion processes and the present degree of damage to the terraces on each of the studied slope sections and terrace complexes. Moreover, when considered in conjunction with the degree of damage to the terraces, if it is known which is the most intensive form of erosion then conclusions can be drawn about the erosive potential of single storms in this mountainous area.

A total of 57 sites were surveyed, of which 3 were unterraced slopes used as pasture, 19 were farmed terrace complexes, and 35 were abandoned terrace complexes. If, when surveying the terrace sites and mapping the land-use forms, it was not possible to conclusively determine whether the terraces of a given complex had been completely abandoned or were merely being temporarily permitted to lie fallow, then because of the generally high

risk of soil erosion they were counted as abandoned terraces. The same procedure was followed in the case of the GTZ project plots, since the damage by erosion to these areas had been, at best, only provisionally checked or repaired.

The most consistent picture of the three studied site types was offered by the three pasture areas on steep slopes. In all three cases, the following symptoms of soil erosion were observed:

Dominant form of erosion:	Incipient gullies (along animal tracks)
Second-most-common form of erosion:	Rills and flow lines
Form of erosion of greatest intensity:	Minor headcuts (30-100 cm high) (cf. Semmel 1978, p. 417)

A quite consistent overall picture also emerged on the studied farmed terrace complexes. The clear signs of sealing, the shallow flow lines and the occasionally observable tendency towards formation of erosion pavements provided irrefutable evidence that pluvial (sheet and splash) erosion was active on all of the farmed terraces. Because of the retaining walls, however, the net effects of these erosional processes were for the most part restricted to small-scale shifting of material from below the retaining walls of the uphill terraces in a horizontal direction towards the raised walls at the front of each terrace. As a result of the splash effect of bombarding raindrops, purposeful channeling of excess water out of terraces, or overflow during heavy downpours, it definitely also frequently occurs that fine soil particles and nutrients with a low specific gravity are washed beyond the boundaries of individual terrace fields. This is visually evidenced by the signs of overflow and mud deposition which can be occasionally observed on walls.

Of the total of 19 farmed terrace complexes which were investigated, eight sites exhibited serious initial damage, mostly in the form of steps (headcuts) created by regressive (waterfall) erosion at collapsed wall sections. At no site was it possible to correlate erosion with degree of exposure, slope steepness, position on the overall slope, or the size of the water catchment area. The only conspicuous aspect was that when terraces with annual crops had been afflicted, the damage had usually been provisionally contained by means of an oval wall of heaped rock or earth (see Photograph 9), while walls in various stages of being repaired were observed in qat and coffee complexes.

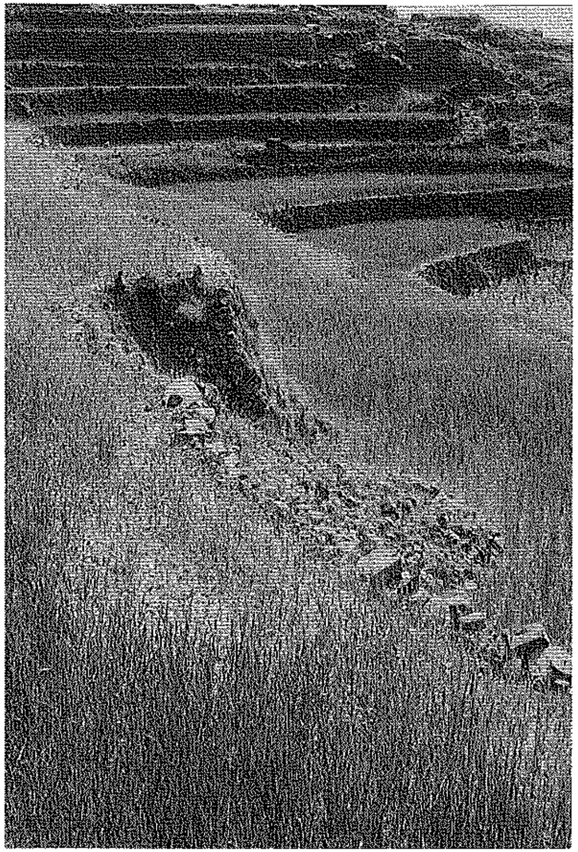
The abandoned terrace complexes made a completely different impression from the farmed terraces and the slopes used as pasture grounds, exhibiting diverse and non-uniform types and degrees of damage. The interviews of local residents which were carried out with the help of the GTZ project quickly confirmed that these differences are indeed the visible result of the terraces having been abandoned during a more or less lengthy period of time. This actually quite trivial realization, which was immediately arrived at after surveying the first sites and for confirmation of which no interviews were really needed, assumed a completely new meaning when it emerged that abandonment of terrace farming dates back further than the onset of massive labour migration at the end of the 1960s. Although this has been without a doubt the largest and most significant phase of abandonment, it had been preceded in this century by two smaller migratory waves provoked by droughts lasting a number of years.

The first of these rural exoduses occurred at the beginning of this century, and was triggered by the so-called "Great Drought", which apparently lasted from about 1903 to 1909 (Betzler 1987). Even before this, in 1902, martial clashes between the politically dominant Zaydis and the Ismaili minority living in the Jabal Haraz district probably prompted many to leave the area (cf. Gerholm 1977, p. 80).

At first glance, slopes once bearing terraces that were abandoned during that time are now difficult to recognize as such. Only when walking across them does one occasionally encounter isolated remnants of retaining walls. According to the informants, during this first phase of abandonment areas east of the tree nursery, near the present-day Sanaa-Al Hudaydah highway, were given up (cf. Land-Use Map). The extent of this abandonment and the subsequent degradation can be appreciated indirectly by the fact that a large village once existed in this area, of which no remains at all can now be found. My field studies suggest that extensive terrace complexes east of Manakhah and on the southern slope of Jabal al Jamimah were also sacrificed to the "Great Drought"; it is now no longer possible to everywhere precisely reconstruct their previous extension (cf. Land-Use Map).

The second wave of abandonment in this century was also provoked by a catastrophic drought, namely that at the beginning of the 1940s (Gerholm 1977, pp. 35 and 57), and according to the two subjects asked about it probably continued into the 1950s. Terrace complexes which were given up during this phase are already so thoroughly degraded that only a few fragmentary remnants of the retaining walls still stand. Unlike the terraces abandoned earlier, however, these areas can still be quite readily recognized as former terrace complexes (see Photograph 10).

Photo 9: Collapsed wall section that has been provisionally repaired (starting point for gully erosion).



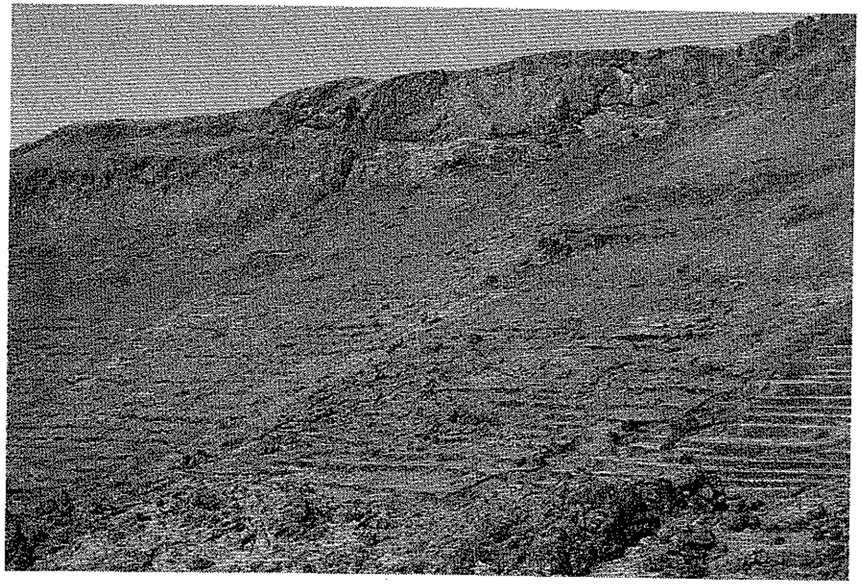
H. Vogel (9/20/84)

The extent of damage on such slopes is between 4/5/5 and 5/4/5, in other words both the dominant and the second-most-common site classes are poor to very poor everywhere, and consequently the poorest site class is in all cases very poor (cf. site classification scheme and survey form in Appendix). The most widespread erosional process on these slopes, which have been largely leveled, is pluvial erosion (sheet, splash and rill erosion), followed by incipient gullying. The form of erosion of greatest intensity is major gullying, although because the soils are now generally quite shallow minor erosion gullies are more frequent.

According to a farmer from Al Hutayb, about 30 years ago, in other words towards the end of the second wave of abandonment, large areas on the steep slope across from (west of) Al Hutayb were given up (see Photograph 10), as well as - according to the sheikh of Al Hajarah - the area now used for agricultural trials by the GTZ project where the unpaved road forks just before Al Hajarah (cf. Land-Use Map). It was probably also during this phase that the settlement on the upper course of the Wadi Shadhb (62.90/67.55), of which only piles of rubble now remain, was abandoned (cf. maps).

The third, still ongoing phase of abandonment began as early as the 1960s as a result of the combined impact of unfavorable natural factors and changed political and socioeconomic conditions.

Photo 10: Completely destroyed terrace complex west of Al Hutayb (looking southwest)

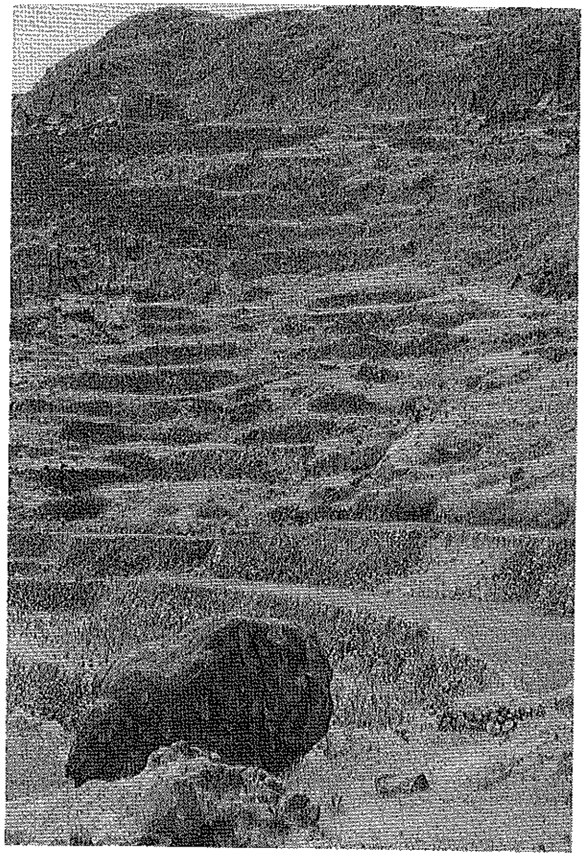


H. Vogel (9/24/84)

When the bloody civil war and with it the self-imposed isolation of North Yemen came to an end in 1969, the third catastrophic period of drought during this century had already begun; it was destined to last until the mid-1970s (cf. Gerholm 1977, pp. 56-57). Under the influence of this persistent drought and the dramatic strengthening of the economies of the Gulf countries at the beginning of the 1970s (the "oil boom"), a massive exodus of male workers from rural areas to the oil-producing states of the Arabian peninsula began. As a direct consequence of this, extensive terraced areas in the study area were abandoned, including some in the immediate vicinity of Manakhah, as well as south of Manakhah in Kahil, Lakamat al Qadi, Al Ayan, Bayi al Mughalad, Jabal, Bani Murrah, Al Hutayb and, more recently, Bayt Hamid (cf. Land-Use Map).

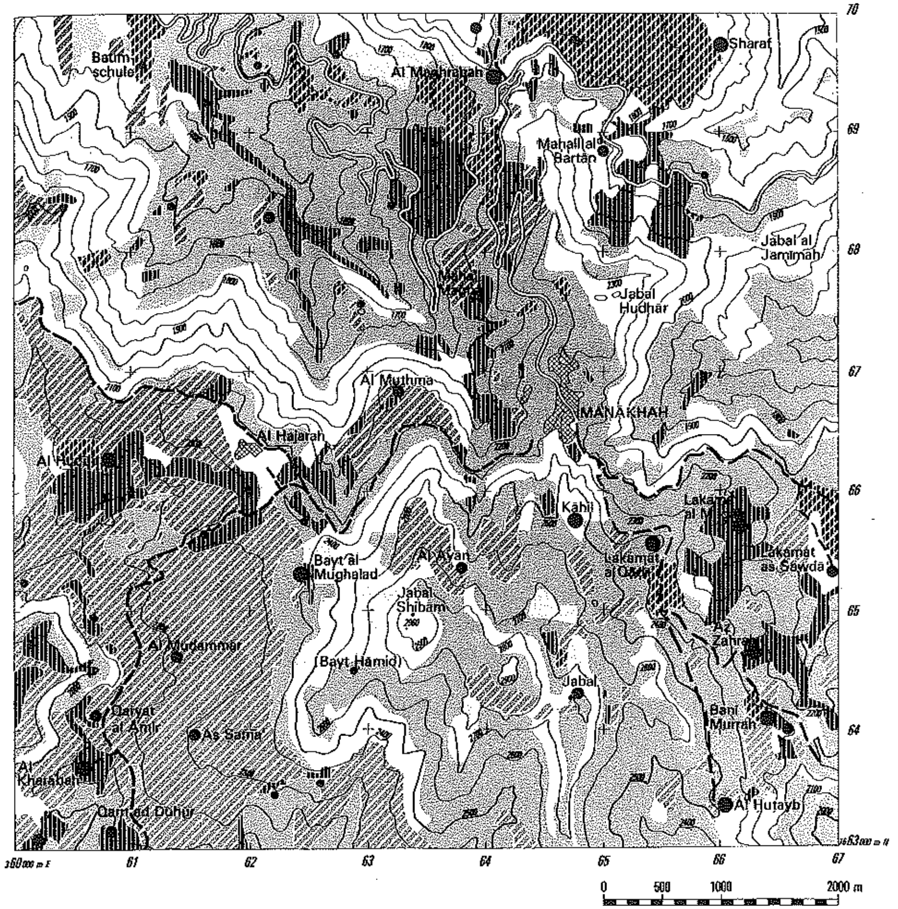
The current degree of damage to terrace complexes abandoned during this most recent phase covers, primarily dependent on how much time has passed since they were last in use, a range from 1/2/4 or 2/1/4 to 2/3/5 and 4/3/5 (cf. site classification scheme and survey form in Appendix). There is no observable connection between the extent of damage to individual terraces and exposure or slope steepness, which can be explained by the fact that all of the slopes fall within the gradient range in which the dynamics of water erosion unfolds its greatest erosive potential when not restrained in any way (cf. Chapter II, section 4, and Chapter IV, section 2 c). There is merely a tendency for the severity of soil erosion to correlate slightly with relative position on the slope and with slope shape. While abandoned terraces on the top of ridges, a fairly rare situation, exhibit relatively little damage due to the lack of runoff sources higher up, on the upper slopes there is a sudden increase in the intensity of erosion, taking the form of severely damaged rock walls and gullying. This prevailing high level of damage extends down to the middle and lower slopes without any further significant increases in intensity, with the single exception of concave slopes that are additionally subjected to lateral entry of water. Those terraces are also subject to accelerated destruction whose retaining walls are made of blocks of tuff, these being highly susceptible to weathering (e.g. the specimen from TU 20).

Photo 11: Intensive gullying on a terrace complex above farmed terraces (map coordinates: approx 65.05/62.85)



H. Vogel (9/23/84)

Land-Use Map



MANĀKHAH
Haraz Mountains

Type of use

Farmed terraces:
- Annual crops ▨
- Perennial crops ▥
- Mixed cropping ▩

Other uses:
- Abandoned terraces ▒
- Pasture ☐
- Wasteland (pasture) ☐

═══ Paved road
– – – Unpaved road

Design and artwork: H. Vogel (1985)

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