4 Introduction to the Physical-Geographical Setting

The Republic of Yemen is located at the southwestern edge of the Arabian Peninsula. It extends from 12°N to 19°N latitude and from 42°E to 55°E longitude. The northern border with Saudi Arabia is not clearly defined, although an agreement has been reached recently.[26] The area is estimated at 550.000 km^2.[27] In the east, Yemen borders the Sultanate of Oman. In the south and west it is framed by the Gulf of Aden and the Red Sea respectively.

The country is separated into two major sections: The Yemen Mountains Massif in the West with the coastal plains (Tihama) on its foot and the eastern part which consists of th Desert (Ramlat as-Sab‘atayn, ar-Rub‘ al-Khālî) and the Eastern Plateau Region. Kruck et al. (1996a) separate the two parts by the main divide between the Red Sea and the Indian Ocean.

4.1 Geology and Geomorphology

The Arabian Peninsula is structurally a part of the African-Arabian plate. Until the Mesozoic, Africa and the Arabian Peninsula formed one continental plate, predominantly consisting of Precambrian gneiss and granite. During the Mesozoic, significant parts of Yemen were below sea level. In this time, massive limestone and sandstone were deposited on the Precambrian basement. They are called Amran group (limestone) and Tawilah Group (sandstone). The first consist of calcareous fissured rocks that reach a maximum thickness of more than 5000 m in the eastern Jawf area [Kruck et al (1996a)]. The average ranges at 800 m [WRAY-35 (1995)]. Spatially, they mainly extend towards the area north of Sana‘a, whereas they are very rare in the Southern Uplands of the Ta‘izz area.

In the western part of Yemen the Tawilah Group comprises two formations [WRAY-35 (1995)]: the Tawilah sandstone and the Medj-Zir sandstone. The Tawilah sandstone consists mainly of porous and fissured sandstones. In some of the eastern parts of Yemen it changes into a calcareous facies [WRAY-35 (1995)]. Locally, the thickness reaches 180 m.

26 Border convention between Saudia and Yemen signed at June 12 2000, Glosemeyer (2001)
27 CSO 1993 Statistical Year Book 1992 in: WRAY-35 (1995)

The Medj-Zir sandstone is not very different from the Tawilah, but incorporates another facies of fossils.[28] Its date of origin is between the end of the Cretaceous and the Tertiary. It shows marks of marine transgressions and regressions. The stratum has a depth of 120 m, but locally reaches 200 m. It stretches around the Yemen Mountain Massive and can be found in several places in Hadramawt where it emerges from below the cover of the Hadramawt Group.

The uplift of the continental plate started with the Tertiary, while the main rising phase was during the Eocene. The tectonic uplift exposed the western part of Yemen. The eastern part of the country remained flooded. Therefore, from the Palaeocene until the Eocene the Hadramawt Group was accumulated to a layer of a few hundred meters depth, consisting of dolomite and limestone with inclusions of gypsum, marl and shale [Brunner (1999)]. Today, the rocks form the surface of the Jawl plateau.

In the western part of Yemen, the significant Tertiary rise of the continental plates by 3000 – 5000 m caused the breaking of the plate into several blocks. The breaklines run NWN to SES – parallel to the Red Sea rift (which was not existing at that time) – or WSW-ENE, orthogonally to it. The vertical shift between the blocks varies and sometimes exceeds 2000 m [WRAY-35 (1995)]. The Red Sea rift began to open in the middle of the Tertiary, but only at the end of the Tertiary the water entered the Bāb al-Mandabs. The stratification of the formations stayed mostly concordant with a small dip to ENE, therefore marine sediments can be found on top of the Yemen Mountain Massif [Brunner (1999)].

This intensive tectonic activity was accompanied by vulcanism along the faults (Yemen Volcanics, also called Trap Series). It created great quantities of flood alkali basalt and subsequently alkali rhyolites, volcanic ashes and tuffs. The vulcanism was spread all over the country but concentrated in the southwest, where it built substantial parts of the Yemen Mountain Massif. Within the Tertiary, volcanic granitic intrusions occurred in several places, especially at the SW incline of the Yemen Mountain Massif.

28 Geukens (1966) in Kruck et al (1996a)

The tectonic movements continued with moderate activity until the Quaternary, resulting in the local appearance of the so-called Quaternary Basalts, also named Aden Volcanics after their significant occurrence in Aden.

4.2 Climate

Detailed and systematic observations or studies on the Climate of Yemen are relatively rare and new. Especially long-term data are not available or often of unclear quality. The available data are sufficient for general classification, but are of poor quality for systematic analysis. As Bruggeman (1997) mentioned: *“Standardisation in observational equipment and practices is low, while recording and the quality of the data are often poor due to difficult access, limited funds and lack of maintenance, spare parts and supervision.”*

First systematical observations were made by RATHJENS et al. (1956) who recorded from August 24, 1931 – March 3, 1934 in Sana‘a.[29] He observed in Sana‘a an annual rainfall of 250.3 mm. Before, the only systematic meteorological observations had been made by Glaser who measured from January – October 1883 450 mm of rain in Sana‘a, and characterised that year as relatively dry.[30] The first longer cycle was measured by J. F. Hansen in Ta‘izz (1944-1953) and Sana‘a (1938-1947) and published by TOFFOLON (1956).[31] The general circulation pattern of the southern Arabian Peninsula was deduced by FLOHN (1965a, 1965b),[32] while Remmele (1989) discussed the climatic conditions of humid and arid months. He used the “Concept of potential landscape-evaporation” provided by LAUER and FRANKENBERG (1981) and based his calculations mainly on the data published in the “Tübinger Atlas des Vorderen Orients”[33] and on his own observations. Another more detailed study on “Rainfall and Runoff in Yemen” provided by FARQUHARSON, et al. (1996) proposed and proved that throughout the country the number of storms is proportional to the mean annual rainfall. Therefore, the mean annual rainfall basically reflects the number

29 RATHJENS et al. (1956) in: VINCK (1960) or REMMELE (1989)
30 RATHJENS et al. (1956) in: VINCK (1960)
31 TOFFOLON. (1956) in: VINCK (1960)
32 in: REMMELE (1989)
33 Sonderforschungsbereich (SFB) 19, “Tübinger Atlas des Vorderen Orients”, University of Tübingen

of storms. The latest compilation of available data and agro-climatic classification, a comprehensive database and GIS-based classification of agricultural zones all over the country, has been supplied by BRUGGEMAN (1997).[34]

Yemen belongs to the outer Tropics and is dominated by the tropical circulation. It has semi-arid to arid climate and is subject to the pattern of the Inter-Tropical Convergence Zone (ITCZ) and the Red Sea Convergence Zone (RSCZ) respectively, while the influence of the latter is still being disputed.[35] This results in an equinoctial rainfall pattern with two rainy seasons, in spring (March-May) and summer (July-September). Commonly, the spring season is aligned with the RSCZ, because the Red Sea is the source of spring rains. The rainy summer season relies on the monsoonal influences of the Indian Ocean provided by the ITCZ. Consequently the summer season is more productive since it is associated with a much larger source of water. Winter rainfalls are seldom and occur mostly in the NW part of Yemen which receives moisture from the Mediterranean Sea.

Further, Yemen is positively influenced by its mountainous relief, causing orographic rainfall at the windward side (W). The annual rainfall reaches a peak of more than 1000 mm/a in the southern mountain near Ibb and plunge rapidly at the eastern slopes to less than 50 mm/a (Ramlat as-Sab‘atayn, ar-Rub‘ al-Khālî, Jawl). Rain usually occurs in convective events, erratic in appearance and of limited spatial extent (< 25 km²)[WRAY-35 (1995)]. With thunderstorms, hail is common and reaches considerable grain sizes. The measuring equipment of the author was partly destroyed by a hail event with grain sizes of more than 2 cm.

4.3 The Study Area

The detailed study area, the Mia‘mirah catchment, is located in the al-Mawāsit – as-Salu area which is a part of the Southern Uplands. The area, located in the former Yemen Arab Republic (YAR), stretches to the former border to the Peoples Democratic Republic of Yemen (PDRY). The political border had a significant influence on the development of the region. Before the existence of the border, the area was much more connected to Aden than to Ta‘izz. Especially older people told the author about their work or relatives in Aden.

34 FAO Project GCP/YEM/021/NET, report not published
35 WRAY-35 (1995)

During the time of the British Governerat in Aden potatoes were grown in Mia‘mirah and carried on foot to the Wadi Sabûn Qadas or Wadi az Zubāyrah for the transported by car to Aden. Labour migration to Aden was common and some of the older people the author met could understand English from their time working in Aden. This connection broke apart in 1967 when the socialists came to power and closed the border. From that moment on the next major city was Ta‘izz which was (and still is) only connected to the area by very bad roads.

The mountainous region stretches from Jabal Sabir south of Ta‘izz until the at-Turbah plateau approximately 40 km further south. It mainly consists of Eocene Basalt[36] (Tb1) with a major granite outcrop, the Jabal Sabir, and a minor outcrop, the Jabal Sami.

In the east and south this mountain complex borders on plateaus of Sandstone (Medj-Zir (Tm) over Tawilah (Kt) series). These plateaus are based on Precambrian Biotite Gneiss (mib/miam). This geologic arrangement is responsible for the development of three major geomorphological structures:

1. The mountains, which have a choppy and rough shape. Jabal Sabir, south of Ta‘izz, is the highest mountain of this ridge and reaches more than 3000 m a.s.l. The main agricultural product is qat. Wherever it is possible, all mountains are covered by terraces. In the lower areas sorghum and other grains are grown. Intercropping with beans is not uncommon. In higher sites (approx. > 1600 m a.s.l.) qat becomes even more prevailing.
2. The plateaus occur in the eastern and southern part of the area. They dip with approximately 7° to the west. Due to their smoother surfaces, these regions are potentially better agricultural areas. The major constrain is the significantly lower rainfall compared with the mountains. Qat is also grown but less important than in the mountain areas. The prevailing crop is sorghum.

36 Geological terminology is adopted by Kruck (1991)

3. The wadis have deeply incised their paths into the mountain massive. In the sandstone they occur as canyons like the Wadi Sāʻilaf Mawqa'ah, a contributory to the Wadi Warazān. They are usually to low for qat growing. Where discharge is persevering, fruit trees like mangos range before corn.

4.3.1 The Miaʻmirah Catchment

The detailed study area is the micro catchment located by the village Miaʻmirah. The size is 36.73 ha and the altitude ranges from 1700 m to close to 2000 m a.s.l.

It belongs to the Al-Mawāsit District of the Taʻizz Government approximately 40 km south (strait line, 70 km by car) of Taʻizz (lon 44°11', lat 13°18') next to the border to As-Salu District. It is a part of the upper watershed of the Wadi Warazan catchment. The population density is above 250 cap/km², population growth is higher than 4 %. Today, the local agricultural production covers about 30 % of the nutrition needs. All other food is imported.[37]

4.3.1.1 Geomorphology, Topography

The catchment is geologically divided in two sections. The lower basis consists of Tawilah sandstone which occurs in both facies, the reddish Tawilah-sandstone (Kt) below and the brighter Medj-Zir-sandstone (Tm) on top. The sandstone submerges below the olivine basalt (Tb1) which forms the top of the catchment.

Photograph 4.1 Semi-pervious channels (in the center of the photo) protect the terraces (on the left) from destructive floods which come from the water harvesting areas (on the right). On the terraces, the plowing creates a corrugated pattern to increase retention.

The ridge and upper part of the slopes are used for water harvesting and goat pasture. They mainly consist of bare rock with interspersed vegetation. Terraces start at different sections of the slope. At the upper boundary they are usually protected from the impact of

37 Data from own observation and interviews.

destructive floods by semi-pervious channels (see photograph 4.1). Those channels control the amount of water and sediment which reaches the terraces. Some of the channels lead the water out of the catchment, which causes the catchment to have multiple outlets.

4.3.1.2 Terraces and Runoff Irrigation

The traditional water harvesting-runoff irrigation scheme simply leads water from the up-slope area in a controlled way to the upper terrace. From there it cascades downwards terrace by terrace. Only in the lower part of the valley the water concentrates in the wadi-channels. This system makes optimal use of the water supplied by the harvesting areas, but it is extremely labour-intensive. The upper terraces are more or less pure "sediment traps" and erosion protection for the lower fields. They need to be maintained every or every other year. The walls must be raised or the sediment removed.[38]

Photograph 4.2 The terraces in the lower part of the photo are cut by a channel which collects the water from the up-slope area above.

This traditional system was changed in the late sixties/early seventies of the last century in several steps.[39] New channels were cut from the uphill run-off areas through the terraces down to the wadi (see photograph 4.2). They cause bypasses and cut off a significant amount of the terraces from water harvesting. Only the adjacent terraces are still irrigated from the channel. The main object of the change was to reduce sedimentation in the terraced fields. The disadvantage of less fields with

Table 4.1 Land use in the Mia'amirah catchment

Land use	***Area***
Terraced agricultural area	183831.42 m²
Water harvesting area	162499.36 m²
Village	5736.03 m²
Graveyard	1415.99 m²

38 Information gained from the farmers.

39 It is assumed by the author that the change was induced by the male labour migration to Saudi Arabia which caused a labour shortage in the migrants' countries of origin. But this could not be proved in the scope of this study.

supplementary irrigation was accepted. Although, reports by the inhabitants indicate that is was a conflict-ridden decision. The new channels eroded within the 30 years down to the base rock of the slope and caused erosion and water losses on the adjacent terraces.

Photograph 4.3 Eroded terrace under construction (lower part is already rebuilt). This Terrace broke down after a series of heavy rainfalls. It is clearly to recognise that the wall leans against the soil. A thick root was growing against the wall from inisde which destabilised the terrace wall. The total length of the terrace damage increased within 3 – 5 days from 3 m to approximatly 12 m because the farmer decided to wait with the repair of the terrace.

Since the time of the channels construction, the number of fallow terraces taken out of tillage has increased. Due to reports of elderly farmers, “all” slopes were terraced except the escarpments. More detailed inquiries by the author lead to inconsistent descriptions for certain locations. But all interviewees agreed on the fact that there have been more terraces in ancient times. In some parts of the upper slopes residual terraces exist. 50 % of the catchment area is today under agriculture, while the other 50 % are used as water harvesting area, village or graveyard (figure 4.1, table 4.2).

Distinguished by the type of front wall, two major types of terraces exist: The most common one is made of raw, piled quarrystones which lean against the soil body of the terrace. The soil body is stable, and the main function of the wall is to protect from erosion. The front wall of the terrace is not strictly vertical but has an angle of approximately 85° – 80° against the slope and does not have full static features. In case the soil body looses, its stability, due to heavy infiltration and insufficient outflow, the terrace can break down. This was observed several times by the author in 1998 (see photograph 4.3). If drainage functions well, a terrace with a damaged wall can stay stable. Depending on this condition, the terraces are fixed properly or poorly. This type is the prevailing type of terrace (more than 90 %).

The second type has a stable "house wall" type wall which is exactly vertical. It is built of properly shaped natural stones without cement. Those "expensive" terrace walls are only used if the terraces have a large surface for agricultural use (see photograph 4.4).

Photograph 4.4 House wall type of terrace (August 1997). The terrace wall is vertical and includes stairs to connect the upper and lower terrace. On both fields sorghum was grown, on the upper one with qat intercropping.

At all terraces, the edge it raised with stones or earth by 5 – 15 cm. This allows ponding of water on the terrace up to several centimeters. Furthermore, also the tillage pattern (described below) enhances ponding. Surface runoff by horton overland flow or saturation overland flow resulting from rainfall on the terraces occurs only at very extreme events (approx. > 40 mm). If runoff from terraces occurs, it is usually caused by additional runon irrigation from the water harvesting areas above.

4.3.1.3 Precipitation and Runoff

Before the placement of the meteorological station in 1997, no meteorological data were available. Bruggeman (1997) indicated the area as "*climatic station lacking*" and for long term observation only the data from the Ta'izz meteorologic station were available. In 1997 and 1998 the precipitation exceeded 1000 mm, although the measurements in 1997 started in June.[40] Both years were considered as "wet" years. Especially 1998 was considered by all interviewed farmers as "the wettest season in approximately 20 years". Therefore, those

40 An unusually late wet period in October 1997 caused severe postharvest damage for the farmers who brought in the crop early.

two years cannot be assumed representative. Nevertheless the seasonal rainfall pattern is similar to Ta'izz, but no correlation exists for daily data. Due to the higher altitude, the total amount of rainfall is significantly higher than the Ta'izz rainfall.

Runoff occurs only sparsly. The event runoff coefficient of the measured events in 1997 and 1998 never exceeded 4 %. Runoff producing areas are, of course, the water harvesting areas, but also other areas with low infiltration capacity as the housing areas, abandoned terraces, canals and the graveyard. The latter is located next to the outlet and has most impact on the runoff measured close by. From well maintained terraces, runoff is almost nil. The runoff occurs immediately with the rainfall event and lasts not longer than a few hours after termination of the rainfall.

4.4 Agricultural Land Use and Agricultural Practices

The prevailing agricultural crops of the area are sorghum (subsistence) and qat (subsistence and cash crop). Sorghum is sometimes grown with millet intercropping. Qat is grown often with sorghum intercropping. The qat area increased from 1990 – 1998 from 2.9 ha to 3.1 ha.[41]

The local sorghum is used for seeds, the import of seeds is not common. Other crops are not grown in significant amount. The author counted the total of 14 coffee trees. Interviews with the farmers indicated that potatoes were grown as cash crop during the British time in Aden, but not for domestic use. In years with late rainfall, winter wheat was sown after the sorghum harvest (1997, but not 1998), but it is not mentioned explicitly by the farmers as an own crop. For sorghum, the growing season starts in May and ends in October and sometimes in November (see farming schedule table 6.7).

The irrigation is 1) pure rainfed or 2) rainfed with additional water harvesting. Groundwater is not used for irrigation. The quantity is limited and the transportation cost of the fuel for pumping is too high. Therefore it is limited to domestic use. There are no additional water sources available for irrigation purposes.

41 mapping by AL-GHORY (1998)

In order to cover the effect of local crop management practices and its impact on transpiration, the farming schedule for sorghum was included into the study. For a better understanding of the local management practices, it is important to know that the goal of production is not only a high grain yield of sorghum, but due to the different uses of different parts of the plants a generally high overall biomass production. In fact, the trunk and leaves, used for animal fodder have a much higher value than the grain.[42] This economic impact causes a plant treatment which will not necessarily optimise the grain yield but is oriented towards fodder and leaf yield. Furthermore, the lower trunk and root, which are not usable as fodder, are used as light fuel.

Because of the use of the leaves as fodder, sorghum is planted even on terraces with limited soil and water conditions where it is very likely that the crop does not fully develop. If the crop withers before the ear develops, the plant can be used as fodder.

The farming schedule (table 6.7) has been compiled accordingly to AL-GHORY (1998) and observations of the author. It represents a generalised scheme based on 10-day intervals (decades), but not on exact dates which could only represent one individual field in one particular year. It is based on the year 1998 and might have a "wet year bias" due to the exceptionally high rainfall.

A large number of measures are known to increase water availability of the crops. Not all of them are practiced anymore. Still common are special plowing and hoeing patterns to diminish surface runoff and increase the retention (see photograph 4.5). Additional plowing is intended to maintain the pattern and destroy capillary tubes in the soil. Elderly women reported that in former times roots of trees were cut off if they grew too much into the surrounding terraces and withdrew too much water from the bodies of the terraces.

As crop treatments, "thinning" – the removal of plants – and "leaf picking" – the removal of leaves from the plants – are known. Both measure reduces the water requirement of the crop due to the reduction of biomass and leaf area. The thinning requires that more seeds are sown than actually have the chance to develop to mature crops. This causes a high probability that always enough seeds will sprout. But it also causes a

42 Estimations by the author evaluate the fodder component as 10 times higher than the grain.

plant density which is too high for the local growing conditions. As a result, the biomass increase is higher than it would be under "standard" conditions. To adapt the plant density to the actual growing conditions plants, were "thinned" – taken out to reduce the final plant spacing. This is usually done several times during the crop development. The removed plants are used as fodder, therefore it can be considered to be a "fodder harvest".

The leaf picking reduces the leaf area and consequently the transpiration significantly. The leaves are also used as fodder. This is a second form of "fodder harvest" and may cause the ear development to be impeded and delayed. Leaf picking is done only once or twice times during the crop development or mid-season stage. Both measures are also done in case of plant deseases.[43]

Photograph 4.5 Special hoeing patterns in the sorghum field (upper left) create shallow ponds which increase the retiontion significantly.

43 Those measures were first explainded to the author as fodder harvest and desease control, the effect to limit water consumption by the plants was not mentioned explicitly. No dry matter data are available to estimate the biomass withdrawal.

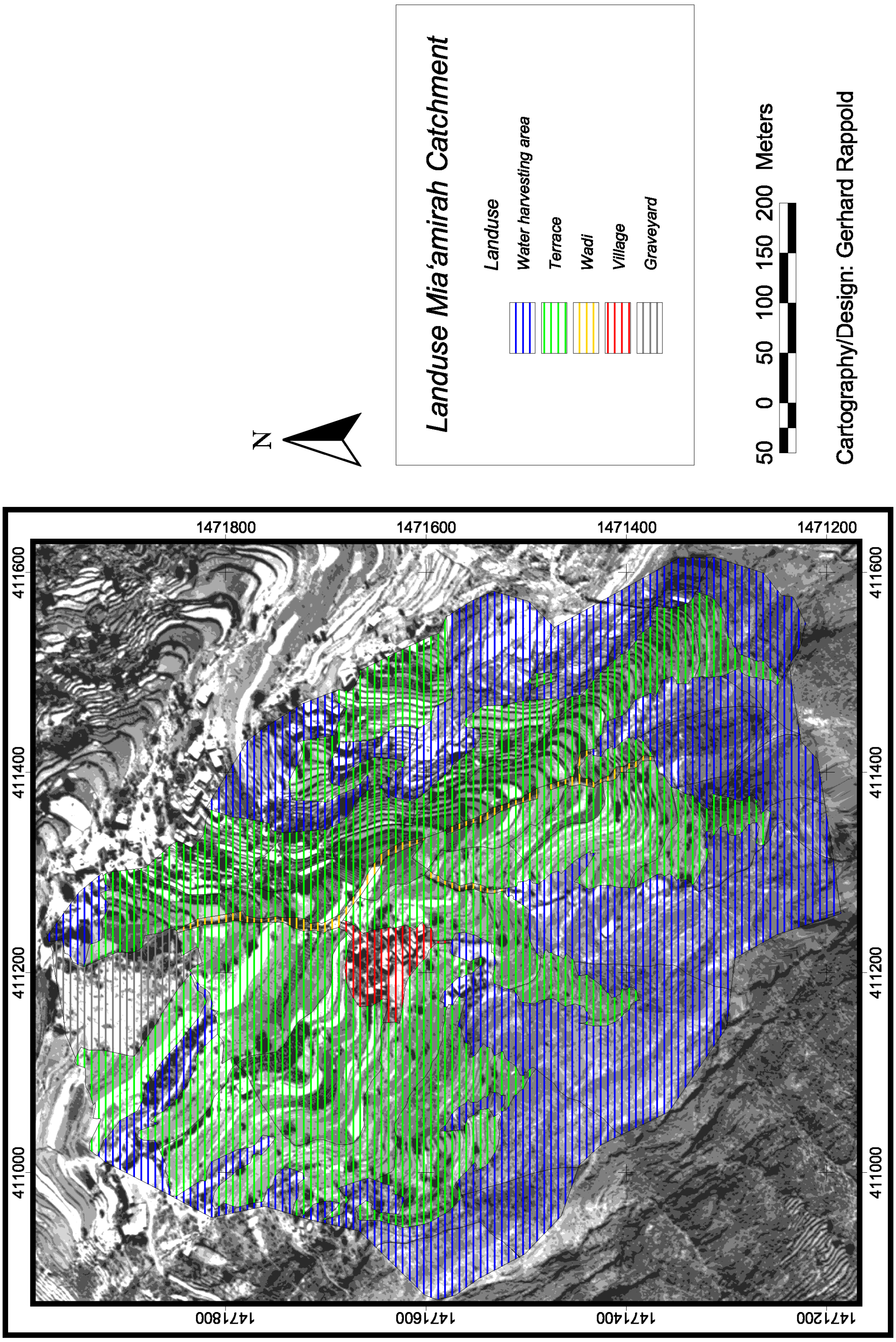

Figure 4.1 Landuse in Mia'amirah

Table 4.2 Farming schedule sorghum [source: Al-Ghory (1998) and own observation]

Month	***Decade***	***Type of work***	***Male/ Female***	***Comment***
March	8 - 9	1st plowing	M	
March	8 – 9	smashing clods	F	Clods which are not cut by the plow will be destroyed. The women walk right after the plow and perform the clod smashing.
March / April	8 - 10	adding animal manure	F	Is also done before plowing.
May	13	sowing sorghum	F (M)	More than 20 grains are used for each sowing hole to ensure the sprout.
May	13	sowing millet intercropping	F	Optional, not in every field.
June	16	thinning of plants	F	[1]
June	16	removal of sediment	M	[2]
June	17	thinning of plants	F	[1]
June	17	adding fertilizer	F	Optional, only wealthy farmers use artificial fertilizer
June	18	removal of sediment	M	
July	20	thinning of plants	F	[1]
July	21	removal of sediment	M	[2]
July	21	picking plant leaves	F	[3] Local arabic: *sour*, reason: plant desease
July	21	hoeing	M	Additional hoeing or plowing break capillary tubes and increases surface ponding.
August	22	removal of sediment	M	[2]
August	24	removal of sediment	M	[2]
August	25	removal of sediment	M	[2]
September	26	picking weed	F	[4]
September	27	picking weed	F	[4]
October	29	bundle sorghum plants	F	Several neighbouring plants are bundled up by some leaves to protect them from breaking off.
October	29	picking plant leaves	F	[3]
October	30	picking weed	F	[4]
November	31	harvesting	F M	The sorghum is cut halfway. Then the ear is cut at the top and the lower part of the trunk remains on the field.
November	31	threshing	M	
November	31	bale and store straw	F	From the upper part of the trunk.
November	32	picking weed	F	[4]
November	32	collecting dry leaves	F	
November	32	collecting trunk	F	local arabic: *kushah*, the lower part of the trunk is used as fuel.
November	33	picking weed	F	[4]
December	35	picking weed	F	[4]

[1] The density of plants is reduced. The removed plants are used as fodder.
[2] The removal of sediment depends highly on the rain and additional runoff irrigation for the specific field. Only at terraces with additional runon irrigation.
[3] All leaves except a few top leaves are removed from the plant. They are used as fodder
[4] Weed control, used as fodder.