2 Major Problems and State of Research

2.1 Agriculture in Yemen

The first evidence of terraced agriculture in Yemen can be dated to 5000 b. p.[1] It developed endogenously until the 2nd half of the last century. After the opening of the country in the seventies, the ancient and prevailing land use, agriculture and related irrigation systems were studied intensively by scientists of many disciplines. Today, a lot is known on pre-industrial indigenous agriculture in Yemen. But there are still many deficits, and especially the lack of systematic climatic and meteorological observations is still obvious. The sources of scientific research on agriculture in Yemen are heterogeneous and diverse. VARISCO (1996), one of the most active American scientists on Yemen, mentions that the history of the Yemeni agriculture has been not yet written and that there is no systematic compilation of all available information. A lot of the information is spread in form of so called "grey literature" and reports among many developing organisations or individual researchers. Even for a scientist with intimate knowledge of Yemen, this material is not accessible at all. Nevertheless, there are major milestones in the scientific sources about Yemen and its agriculture.

An important geography of Yemeni agriculture in German was written by KOPP (1981). It provides an integrated overview and tackles many of today's problems and constrains. Another classical interdisciplinary reference is DAUM (1987). BRUNNER (1999) recently published an actual physical-geographical overview about Yemen. VARISCO provides several important contributions on Yemeni agriculture and irrigation systems (VARISCO 1982, 1989, 1991, 1996) from an anthropologist's point of view.

Furthermore, there are plenty of regional field studies, but there is a shortage of systematic evaluation and monitoring of relevant agricultural parameters. The most relevant source on Yemeni agriculture and runoff irrigation based on field experiments was written by EGER (1987). BAMATRAF (1994) mentioned that EGER's fieldwork, which was conducted from 1981 – 1984, was one of the first quantitative studies in Yemen and complained that no follow-up work has been carried out although EGER recommended

1 BRUNNER (1999)

further activity. Further, various volumes of the series "*Jemen Studien*" edited by Horst Kopp and related publications are to be considered when studying agronomy-related topics as "*Soil Erosion in Terrace Farming*"; VOGEL (1992). A recent publication by KOHLER (1999), "*Institutionen in der Bewässerungs-Landwirtschaft im Jemen*" provides important information on water management issues and institutions in Yemen.

2.2 Water Scarcity, Aridity and Drought

Water availability is one of the key questions for human existence, and the absence of water has many faces and definitions. While aridity and drought are well-known phenomena on the local or regional level, its global magnitude and social implications are a relatively new issue.

Aridity or arid climate is defined by hydrologists as a "*climatic condition when the average annual evapotranspiration is larger than the precipitation*".[2]

Surprisingly, the definition of drought is quite vague. BERAN and RODIER (1985) suggest the following: *"The chief characteristic of the drought is a deep freeze of water availability in a particular period over a particular area."*

This is not a very clear definition. But it points out the differences between drought and aridity. Drought is a temporary phenomenon, a deviation from the normal condition, while aridity stands for permanent water scarcity. The NATIONAL DROUGHT MITIGATION CENTER (NDMC) features further operational definitions of drought which are defined by certain measures, e. g. by a threshold of 75% of the average precipitation for a given time interval. WILHITE and GLANTZ (1985)[3] approach a disciplinary perspective of drought and distinguish 4 categories:

- ***Meteorological drought****: Usually expression of precipitation's departure from normal over some period of time. Reflects one of the primary causes of a drought.*
- ***Hydrological drought****: Usually expression of deficiencies in surface and subsurface water supplies. Reflects effects and impacts of droughts.*
- ***Agricultural drought****: Usually expressed in terms of lack of soil moisture for a particular crop at a particular time.*

2 Wörterbuch der Allgemeinen Geographie (1992) translation by the author
3 quoted from: DEMUTH, S and K. STAHL (2001)

- ***Socioeconomic drought****: The definition associates droughts with supply of, or demand for an economic good.*

To conclude: aridity is the complementary condition to humidity and a measure of permanent absence of water. A drought is a period of 'drier-than-normal conditions that results in water problems.'

Under both conditions, the population has to respond to the limited availability of water. In arid conditions this may result in a continuous adaptation, while preparation for drought events is a preparation for extreme events that occur with a certain probability.

The measure for water availability depends on the size of the population and its lifestyle. Therefore, it is surprising that the actual water requirements per capita and the measure for water scarcity are a relatively new issue. The Swedish hydrologist MARLIN FALKENMARK (1989) was one of the first who considered the total water need of all aspects of life. She started from an assumption of 100 l/day (36.5 m³/y) as the minimum requirement and came to the result that an annual water need per capita of almost 1600 m³ or more is necessary for a moderate – good lifestyle. The largest part (69 %) was 'hidden' in human nutrition, supplied by agriculture.

In humid climate, the water required for agricultural needs is provided "for free" by rain. This is not the case in semi-arid to arid conditions. FALKENMARK (1989) stated two benchmarks for water shortage: 1600 m³/y as the threshold for water stress and 1000 m³/y as the threshold for water scarcity. This opened the eyes of many scientists and politicians and within a short time a comprehensive amount of publications[4] approaching the problem and the thresholds were widely accepted by organisations like the World Bank (1992). Comparing the renewable water resources of a country, region or catchment with the water demand of the population, it is possible to calculate a water stress index based on the benchmarks above. It expresses the renewable water resource per capita.

The calculation of the water stress index raises the question of the coping possibilities of the society. TURTON and OHLSSON[5] provide some methodological work. They suggest that beside the pure water availability (or absence) per capita given by the water stress index the

4 e. g. GLEICK (1993), POSTEL (1996), ENGELMAN (1993, 1995)
5 TURTON (1999a,b), OHLSSON (1999)

possibility of the adaptation of a society has to be considered. Ohlsson describes it as "*first order scarcity*" of natural resources and "*second order scarcity*" of social resources to cope with or adapt to the first order scarcity. This coping capacity depends mainly on the prosperity and educational level of the society. As a measure for the social adaptation ability Ohlsson (1999/2000) suggests the use of the UNDP Human Development Index (HDI), which includes three variables: life expectancy, educational attainment and real GDP per capita. The water stress index introduced above divided by the HDI will result in an social water stress index (SWSI). The use of this index re-scales the list of water-stressed countries. Countries like Poland or United Kingdom will not be considered as water stressed while others like Niger, Afghanistan, Eritrea will move from "relatively sufficient" to "water stress".

For Yemen, the annual water resources are estimated at 5.2 km³/y which is the equivalent of 445 m³/y/cap in 1990 and 346 m³/y/cap in 1995.[6] The significant decrease within this short time reveals the extreme population growth. These figures demonstrate the national situation of Yemen which is partly compensated by exploration of fossil water and water mining, with the consequence of constantly dropping groundwater levels. A more sustainable but economically conflicting measure to diminish water consumption are food imports.

2.3 Water Harvesting and Runoff Irrigation

Water harvesting in its broadest sense can be defined as the collection of runoff for its productive use, Siegert (1994). It is conducted in semi-arid to arid areas where rainfall is not sufficient to supply for agricultural production or domestic use. The principle is the collection of precipitation and its transformation into surface runoff in one area, that contributes a target area or a storage tank (see figure 2.1). The term "water harvesting" was first used by Geddes (1974) [quoted from Pacey and Cullis (1986)] to describe "the collection and storage of any farm waters, either runoff or creek flow, for irrigation use." The water harvesting schemes reach from roof collection to large scale runoff irrigation

6 The sources differ significantly, e. g. : Gleick (1993): 2.5 km³/yr; Engelman (1993): 5.2 km³/yr.

schemes like the ancient Marib dam. On principle, they can be distinguished into 6 major groups [after: PRINZ (1996)]:

a) roof top water harvesting
b) water harvesting for animal production
c) inter-row water harvesting
d) microcatchment water harvesting
e) medium-sized catchment water harvesting
f) large catchment water harvesting

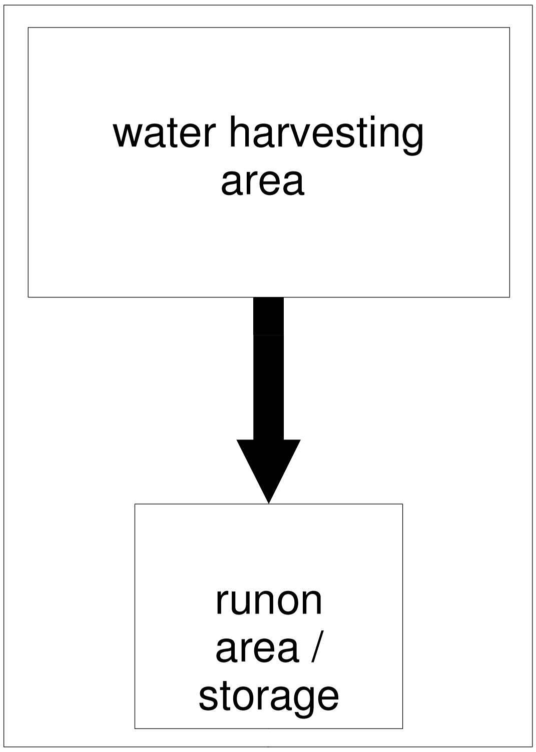

Figure 2.1 Principle water harvesting scheme

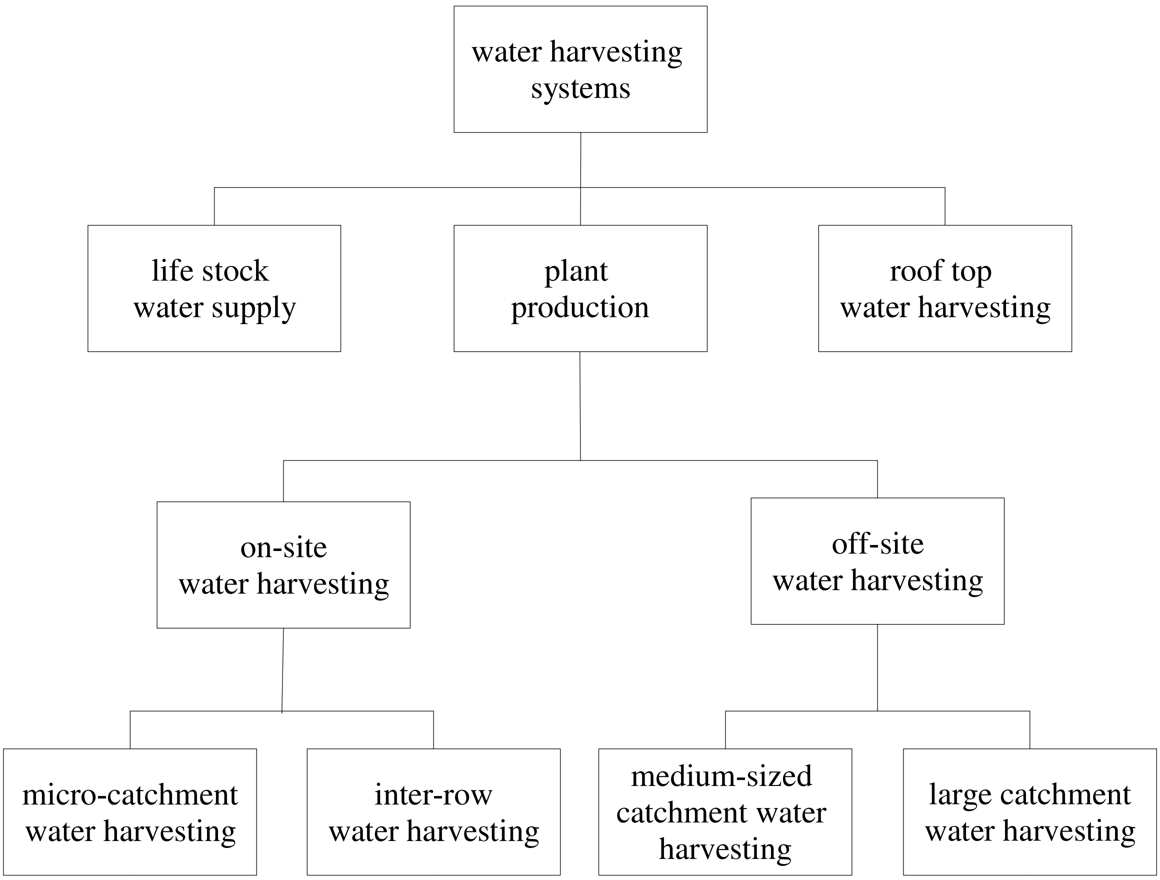

Figure 2.2 Hierarchical water harvesting classification (by the author)

The different groups above can be classified into “non-plant production schemes” (a, b), on-site (c, d) and off-site (e, f). The first group (a,b) will not be considered in this study. Figure 2.2 depicts a hierarchical scheme of water harvesting methods.

Inter-row water harvesting schemes: The collection area is directly adjacent to the crop row. In sloping areas they are called “contour ridges”. The distance between different rows increases with aridity (figure 2.3).

Microcatchment water harvesting systems: They collect the water from a small area (approx. 1.5 – 2 m between ridges) to supply for a single tree or bush. Figure 2.4 depicts the well-known micro-catchments in the Negrev desert.

The strongest advantage of 'on-site' water harvesting is the high efficiency. Short distances from the harvesting area to the irrigated area prevent transmission losses and result in high runoff coefficients. But it faces the low cropping density including a significant loss of potential land. Furthermore, it requires adopted tillage techniques.

Medium-sized catchment water harvesting systems range from 0.1 – 200 ha. The rainfall is collected at an up-slope area and distributed on terraces at the bottom slope or on fields in flat terrain (figure 2.5). PACEY AND CULLIS (1986) refer to it as “water harvesting from external catchment system” which describes it more precisely. The water harvesting-terrace irrigation of Yemen belongs to this category.

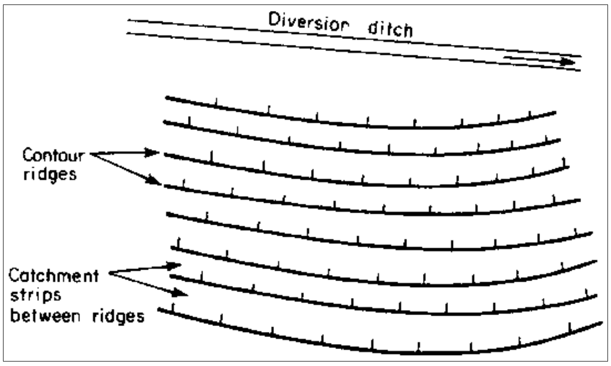

Figure 2.3 Contour ridges scheme after: CRITCHLEY and SIEGERT *(1991)*

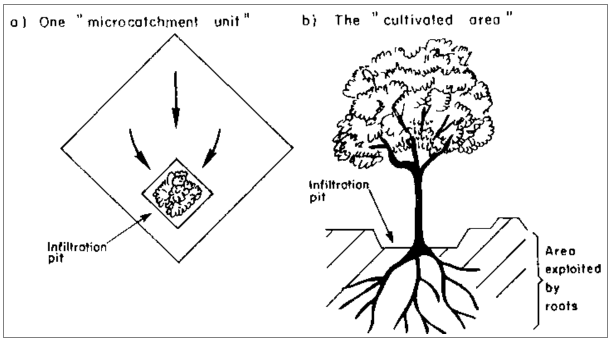

Figure 2.4 Single bush water harvesting scheme after: CRITCHLEY and SIEGERT *(1991)*

Large catchment water harvesting works in a similar way but on a larger scale. The ancient Marib dam belongs to this type of water harvesting [BRUNNER (1999)]. It requires larger constructions and more complex irrigation channel systems. The advantage of off-side water harvesting schemes are that field work can be done conventionally and the runoff-runon area relation can be increased by magnitude in relation to on-site schemes. Disadvantages are higher transmission losses. The result is, that often only a part of the collecting catchment contributes to the water harvesting. This reduces the efficiency of the schemes.

Water harvesting schemes existed in all inhabited semi-arid to arid regions and were a common type of irrigation. But the European expansion and the technological development with the industrial revolution lead to a steady increase of conventional irrigation, and water harvesting systems took second place [PRINZ (1996)]. The conventional irrigation increased dramatically. The irrigated area today reached its limits world wide and no further significant increase is possible. Because of the concentration on conventional irrigation, which better meets the requirements of commercial cash crop oriented agriculture [OWEIS et al. (1999)], only very few research activities existed before 1950 [PRINZ (1996)]. Many studies came from the field of archaeology, history or anthropology [EVENARI and KOLLER

(1956): Ancient Masters of the Desert; VARISCO (1996): Water Sources and Traditional Irrigation in Yemen] rather than from an agricultural background.

But in view of an increasing world population, water harvesting schemes are getting constantly more attention and a number of compilations on water harvesting were published: PACEY and CULLIS (1986), CRITCHLEY and SIEGERT (1991), CRITCHLEY et al. (1992), FAO (1994). Most of them focus on design and implementation issues within the scope of development projects or are related to soil conservation, HUDSON (1987). Short overviews on principles of water harvesting are provided by BEN-ASHER and BERLINER (1994) and OWEIS et al (1999).

Figure 2.5 Medium size water harvesting CRITCHLEY and SIEGERT (1991)