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Annex 1

Case study
Rainwater Harvesting

Final Report
Agricultural Technologies for Developing Countries

STOA Project "Agricultural Technologies for Developing Countries"

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- Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe
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STOA Project "Agricultural Technologies for Developing Countries"

Rainwater Harvesting

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Prof. Dr. Klaus-Dieter Balke

Universität Tübingen
Institut für Geowissenschaften
Sigwartstr. 10
72076 Tübingen
Germany

1 Characteristics of the Production System

Definition

It has been shown that the largest challenges of poverty-related under-nutrition are found in arid, semi-arid and semi-humid regions of developing and threshold countries (Falkenmark & Rockström, 1993, in SIWI report 11, 2001) and even in humid areas with longer lasting dry seasons. In such regions the methods of Rainwater Harvesting RWH can help to achieve an optimal use of rainwater for drinking and agricultural purposes. If the food gap, which many developing countries are experiencing at present, is not filled enormous regional and global problems will arise in the near future regarding the socio-economic development and social stability of the countries, together with huge damages in the environment. RWH farming is one of the measures to diminish these problems.

Rainwater harvesting (RWH) is the collection, filtration and storage of local rainwater and surface runoff for domestic consumption, livestock and irrigation. Precipitation falling on a catchment area (runoff area) is conducted to a retention or cultivation area (runon area). The water can be stored in the soil as productive soil water for feeding plants immediately or in cisterns and reservoirs for later use. The various kinds of RWH for agricultural application can be seen as water collecting and supplying methods ranging between rainfed and irrigated agriculture.

RWH is applied in water scarce regions characterized by irregular and scarce precipitation, longer lasting dry periods between seasonal or irregular rainfall, ephemeral rivers and no shallow groundwater of appropriate quality. Where RWH is applied the size of the productive land is enlarged.

There are several RWH techniques to catch precipitation. In many dry and semi-dry regions around the globe the water supply for human beings, cattle and small scale farming depends mainly or completely on RWH.

Examples demonstrate that the crop yield of rainfed cultivation can be doubled or even quadrupeled by using techniques of RWH because the catchment areas deliver an increased quantity of water to the cultivated areas so that the plants can consume water over a longer period of time. Such results also require an optimum time of planting, the choice of appropriate crops, a good management of soil fertility, pest control and crop rotation (Hatibu & Mahoo, 2000). Depending on the pitting methods used, the crop yield may increase by 40 % (Prinz et al.)

Key Elements

The quantity of water which can be collected by RWH depends on the local rainfall (quantity, density, frequency), the temperature, the morphology of the site, the outcropping rocks, the soil cover, and the size of the catchment area. In rural areas it is often possible to supply single small scale farmers and farming communities with water for domestic use, adjusted farming, and animal husbandry.

RWH arrangements usually consist of a catchment area, a sedimentation and filter unit, a conveyance system, and a storage facility. Systems for direct farmland irrigation often only consist of alternating catchment areas and cultivated segments. The size of catchment and cultivation areas ranges from some ten square meters to large pieces of land. Often, the catchment areas are 5 to 10 times larger than the appertaining cultivated areas, sometimes even more. RWH storage systems range from simple PVC tanks to big reservoirs located on the surface or in the subsurface with volumes from several to hundreds of cubic meters.

RWH systems have to be designed according to the local conditions such as rainfall pattern, evaporation losses, kinds of rocks and soils, morphology, water demand, and the purpose of use (domestic water, livestock, irrigation). There is no superior scheme that can generally be applied, the design has to be worked out specifically for each local situation. Long-term experiences should be taken into consideration, too. Another consideration is the fact that constructions and installations for RWH are typically cheap and can be done by local people.

The **precipitation** governs the quantity of water that can be caught and collected, its distribution during the year determines the needed storage capacity. During rainfall most of the water runs downwards as surface runoff and executes erosion, but it should be used for wetting the soil of cultivated land.

Evaporation and **evapotranspiration** (evaporation plus the transpiration of plants) cause water losses especially in hot regions. The highest evaporation rates are found where the water surface is exposed to the open air. Therefore, cultivated areas have to be designed in such a manner that no pools can form upon the surface.

The **morphology** of an area determines the kind and size of RWH installations and governs the collectable quantity of water as well as the amount of soil which is eroded at higher altitudes and precipitated at lower locations.

The outcropping **rocks** around and below RWH sites influence the quantity of runoff and seepage corresponding to their permeability and storage capacity. Hard rocks such as sandstones or granites can yield a lot of runoff if they are not crushed by many joints and fissures.

The **soil** in the cultivated part of RWH sites can store water according to its depth and storage capacity. Clayey soils only permit small infiltration rates, because of their low permeability, but they have a high water storage capacity, whereas sandy soils, because of their high permeability, allow high infiltration rates but the storage capacity is small. The best results can be achieved with loamy soils having medium values of both permeability and storage capacity. The soil must have a minimum depth depending on the chosen plants to be able to store enough water to cover the plant´s water demand. Moreover, a certain content of humic matter and an appropriate tillage are necessary for getting satisfying crop yields.

Regarding these aspects, conservation agriculture is a also appropriate for small scale farmers for resource-saving crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. Conservation agriculture is characterized by three related principles, namely:
continuous minimum mechanical soil disturbance,
permanent organic soil cover,
diversified crop rotations in the case of annual crops or plant associations in case of perennial crops (FAO, 2008).

Soil as a habitat for plants must be loosened after the harvest. Normally, this is done by using a plough with the consequence that after a certain time the organic matter and the fertility of the soil are reduced and its structure is destabilized. In a soil that is not tilled with a plough, the crop residues remain on and below the surface and produce a layer of mulch (dead vegetation) that protects the soil from physical impacts of rain and wind and inhibits evaporation of soil moisture. Many organisms grow in the soil, decompose the mulch to humus, stabilize the moisture, the temperature, and the structure of the soil, increase the water seepage into the soil, and reduce surface runoff and erosion. Thus, conservation farming promotes the agricultural potential of cultivated areas and its adoption is particularly recommended for small scale farmers. FAO actively supports conservation agriculture, especially in developing and emerging economies such as Ghana (Boahen et al., 2007), Kenya (Kaumbutho, Kienzle, 2007), Tanzania (Shetto, Owenya, 2007), Uganda (Nyende, Nyakuni, Opio, Odogola, 2007), Zambia (Baudron, Mwanza, Triomphe, Bwalya, 2007).

Crop residues are left on the soil surface, but cover crops, "green manure", may be needed during fallow periods if the gap is too long between the harvest of one crop and the establishment of the next. Cover crops are mainly grown for their effect on soil fertility or as livestock fodder. There are various cover crops such as leguminous, clover, lupins, lentil, alfalfa, grass, etc. that can be chosen according to the regional conditions.

The **plants** to be cultivated in a RWH scheme should have a limited water demand, a short vegetation period and a tolerance to drought and waterlogging. Trees are relative sensitive to moisture stress during the establishment stage compared with their ability to withstand drought once their root system is fully developed (Mishra, 2006). For each region the most appropriate crops must be chosen according to the natural conditions (availability of water, soil composition, etc.), the demands of the plants and the acceptance by the population. As fertilizers natural plant remnants or manure should be used, chemical fertilizers only in small quantities when necessary and. In regions with RWH fed agriculture various plants are cultivated for instance almonds, apricots, barley, beans, cabbage, cassava, citrus, dates, figs, groundnuts, lentils, lettuce, maize, melons, millet, olives, onions, peaches, peas, pepper, sorghum, squash, tomatoes, wheat, etc., and sheep and cattle are fed as well.

The **chemical condition** of the rainwater influences its application for the watering of plants. Numerous studies have examined the quality of rainwater in industrialized countries but little information is available about the situation in rural areas of developing countries. Therefore, it should be checked whether the rain contains contaminations (salts, heavy metals, organic compounds, bacteria, viruses, etc.). Especially endangered are locations situated leeward to industrial plants (quarries, mining, oil refineries) and urban areas.

To summarize, the various techniques to catch water by RWH depend on some basic criteria:

- rainfall conditions (annual amount, frequency, density, etc.),
- potential evaporation, transpiration,
- kind of catchment area (runon areas, rills, gullies, pavements, etc.),
- soil types and depth,
- morphology, slope steepness,
- water demand (human beings, animals, crops),
- water quality (salinity, turbidity),
- availability of land,
- assessment of possible risks for downstream areas,
- economical aspects.

Besides the techniques described in the following other techniques were developed worldwide in former times according to local conditions.

Key Technologies

Many special techniques to catch rainwater were developed in the past. When selecting a RWH method the most important considerations are especially the climatic factors and the morphology of the site as well as whether the water shall be collected in a cistern or directly conducted to a cultivated area.

Rainwater Harvesting with Cisterns

If collected rainwater shall be used later it can be stored in cisterns and reservoirs which are located in depressions and in semi-closed basins. The surface of the catchment area may consist of a natural rock surface, artificially compacted soil, it can be cemented or sealed with plastic sheets. The water is conducted from the catchment area into the appertaining storage chamber. The size of the catchment area and the storage chamber has to be calculated based on the water demand and the rainwater yield.

A small sedimentation basin must be added in front of the water entrance of cisterns for the precipitation of silt, clay and other suspended material carried along by the runoff. Such basins can also be filled with sand in order to improve the cleaning effect by filtering. The harvested water can be stored above-ground or below-ground but an adequate enclosure is essential to prevent contaminations. The enclosure should also ensure dark storage conditions in order to avoid algal growth and the breading of mosquito larvae. Below-ground storage facilities have the advantage that the water remains relatively cool and evaporation losses will be reduced to a great extent.

Simple cisterns can be constructed by the farmers using local material. Therefore, the financial risk is very limited or nearly nill and the cost for maintenance is relatively low.

A simple version of a cistern is an excavation within a loamy, more or less impermeable sediment, see Fig. 1.1. The catchment area above ground is delimitated with a small bund made of rocks and loam that directs the rainwater to the entrance of the cistern. After having passed a silt basin the water enters the cistern. To block the entry of animals into the cistern the inflow pipe is secured with a thorny branch.

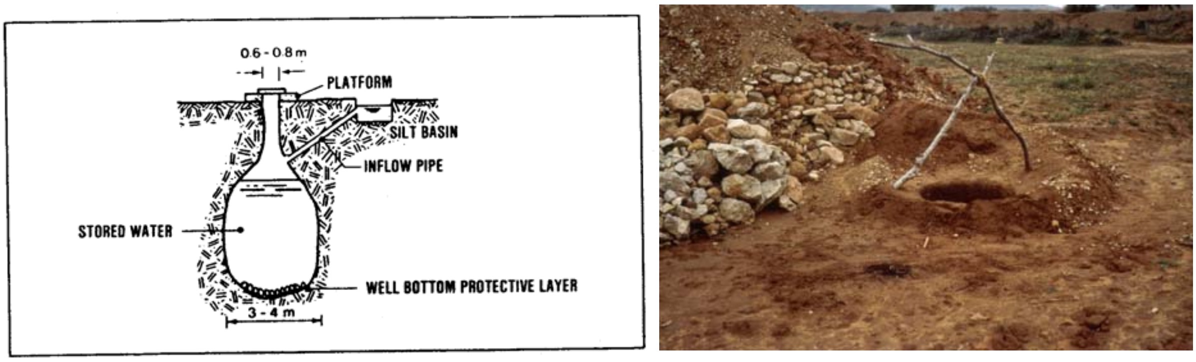

Fig 1.1 left: Scheme of simple subsurface cistern (Hofkes, 1983), right: simple construction, Tunisia (Balke, 1997)

Larger quantities of water can be stored in cisterns with barrel vault, see Fig. 1.2.


Fig. 1.2: Barrel vault cistern, Tunisia (Balke, 1996)

A common version is the combination of a cemented catchment plate with a storage chamber below ground, see Fig. 1.3.

Fig. 1.3: RWH facility with cement plate, water entrance [in front of the person], storage chamber [in the edge below the plate], opening for water extraction and overflow outlet, Tunisia (Balke 2007)

Extended yards, especially if they are paved, may deliver big amounts of rainwater.

Large cisterns of various designs can be positioned at the deepest point of a depression. They may be constructed with concrete or masonry, for instance and partly filled with sand. In the middle of the cistern a well is made for the water extraction, see Fig. 1.4.

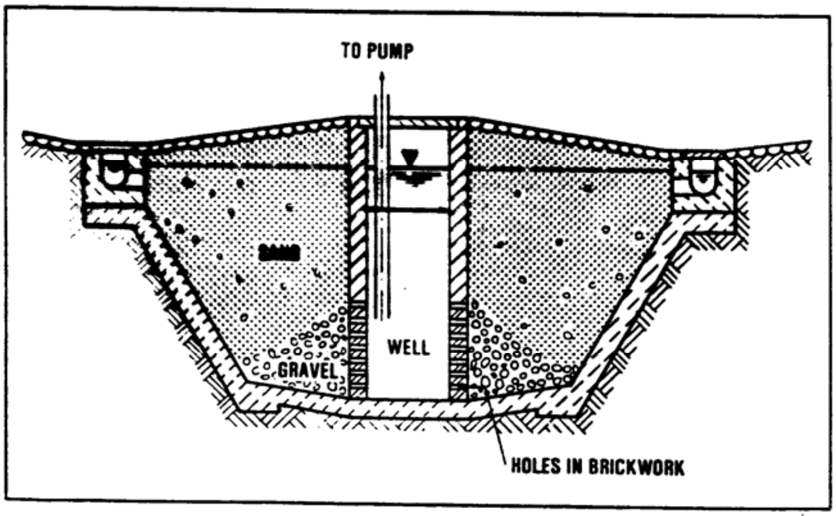

Fig. 1.4: Venetian Cistern (Hofkes, 1983)

In mountainous hard rock regions cisterns can be positioned at sloping and steep locations where surface water runs downwards in small zones or trenches during rainfall events. Additionally, groundwater can be caught out of the rocks with a boring or a gallery, a few metres in length, advanced from the cistern into the adjacent rocks, see Figs. 1.5 – 1.7. The cisterns can be caved into the rocks or built of stones or bricks.

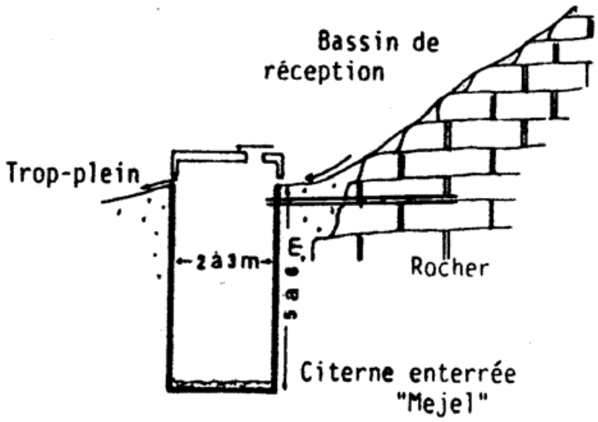

Fig. 1.5: Mejel (Mamou, 1981)

Fig. 1.6: Mejel, Tunisia (Balke, 1997)

Fig. 1.7: Fouskia, Tunisia (Balke, 1997)

Rooftop Rainwater Harvesting

RWH can also be applied using roofs, see Fig. 1.8. The rainwater is conveyed to a storage tank that should be located close to the house but far from latrines. In order to minimize water losses by evaporation the runoff from the roof into the collecting tank should be as quick as possible; therefore, even flat roofs shall have a certain inclination, and the conveyance system shall be in a good and waterproof condition. It is necessary to reject the first “foul flash”, i.e. the rainwater falling at the beginning of a rainfall, because it carries the dirt that precipitated upon the roof during the period before.

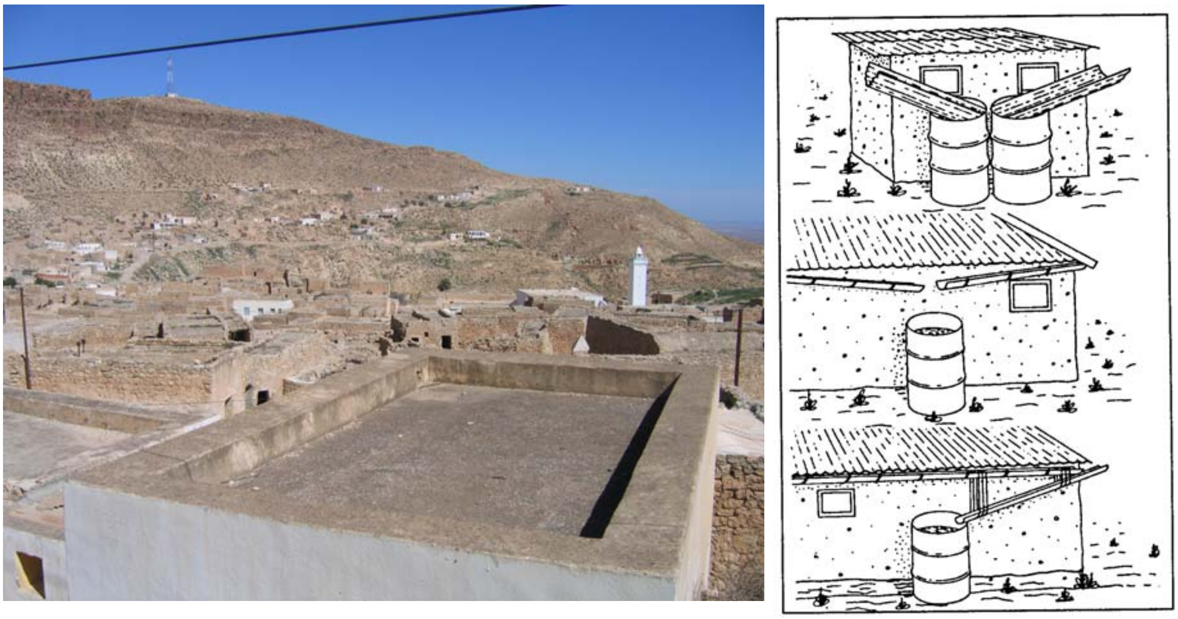

Fig. 1.8: left: RWH on roof, Toujane, Tunisia (Balke, 1994), right: Schemes of RWH from simple house roof (Pacey & Cullis, 1986)

Rainwater Harvesting in Mountainous Regions

In mountainous regions rainwater and surface runoff can be collected in valleys and on slopes.

In small valleys a series of **micro dams** of about 2 to 4 m height can be constructed , located perpendicular to the valley line one below another, see Fig. 1.9.

Fig. 1.9: Micro dams, Tunisia (Balke, 1995)

The dams, delimitating the cultivation area (retention area), are made of loamy soil and equipped with a spillway (overflow) that is reinforced by a layer of rocks. Without such a rock-protected spillway the crest of the dam and finally the whole dam will be destroyed by overflowing water during heavy rainfall. The bottom of the spillway should be only 10 to 20 cm higher than the surface of the cultivated area, otherwise a pool can form before the dam after rainfall. Most of the excess water in this pool evaporates without any use for the cultivated plants, see Fig. 1.10. Generally, water losses through seepage and evaporation should be reduced to a minimum but the soil should be wetted over its whole depth.

The soil for the cultivation area can often be collected in the surroundings and placed before the micro dam. Moreover, the runoff water entering a micro dam area carries a certain quantity of eroded sand and soil. A portion of it will be

Fig. 1.10: Excess water in the retention area, Tunisia (Balke, 1995)

deposited in the retention area and elevate the soil surface in the course of time. When that happens, the dam must be elevated, too, or a portion of the soil must be transferred to another place where the soil cover is still too thin.

The plantation may consist of one or more trees, corn, vegetables, etc. Dependent of the steepness and shape of the valley and the height of the dam the cultivable land gained this way may be between a few and a few hundred square meters in size.

Infiltration Trenches

On slopes carrying a cover of soil or loose sediments small infiltration trenches can be deepened parallel to the contour lines. The ditches retain rainwater that waters trees, bushes or grass, see Fig. 1.11. Additionally, the erosion at the slope will be reduced.

Fig. 1.11: Infiltration trenches, Tunisia (Balke, 1998)

Hill Catchment

The catchment area of a RWH arrangement can comprise the upper part of a hill. In this case a collecting wall or a bund of loam, reinforced by rocks, must be built that surrounds the hill, slightly dipping towards an outlet, and conveying the water into a storage basin or cistern, see Fig. 1.12.

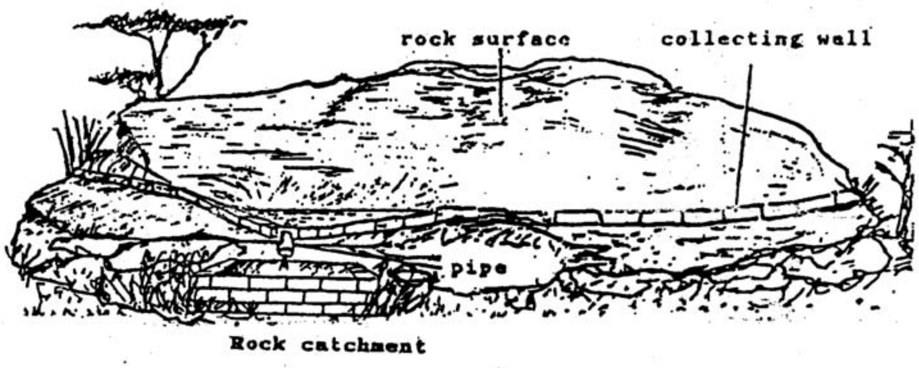

Fig. 1.12: Water harvesting around a hill (Rocheleau, 1986)

Reservoirs of Micro Dams

In mountainous as well as in flat regions rainwater can be collected in small **reservoirs** delimitated by micro dams of 3 to 5 m height, located in shallow depressions or valleys. The dams are built of rocks and loam and contain a spillway. The water can be used for livestock and irrigation.

Rainwater Harvesting in Flat and Slightly Dipping Areas

In flat and in slightly dipping areas several techniques can be applied in order to catch rainwater and surface runoff.

Subterranean Embankment

In areas where the uppermost layer above more or less impervious rocks consists of permeable soil, weathered rocks, or sediments of about 1 m thickness, subterranean embankments can be used for RWH. They consist of a circular or convex trench down to the bedrock, see Fig. 1.13. The bund, made of loamy material, rises 0.50 to 0.75 m above the surface. Upstream the bund a layer of filter sand has to be placed.

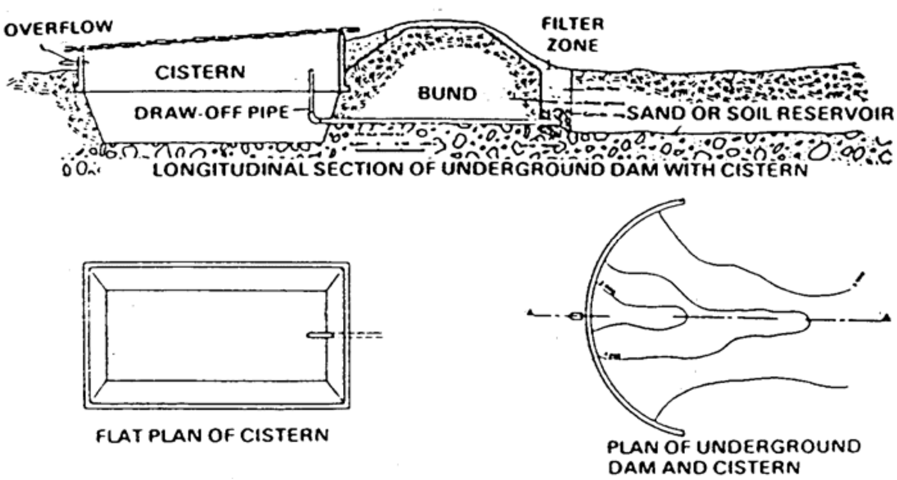

Fig. 1.13: Subterranean embankment (Power, 1985)

Rainwater is stored before the bund, it seeps through the filter zone, and finally flows through the draw-off pipe into the cistern.

Subterranean Catchment

Along the contour lines of slightly dipping landscapes, in inundation zones, or in valleys, subterranean catchments can be deepened into the bedrock [B], see Fig. 1.14. Rainwater seeps through the sand layer [A] and the gravel pack into the collector pipe [D] and is conveyed to a cistern. For stabilization purposes the trench is equipped with steel sheets [C], stones, bricks or concrete. The construction is 1 to 2 m deep, 2 to 4 m wide, and up to a few hundred meters long.

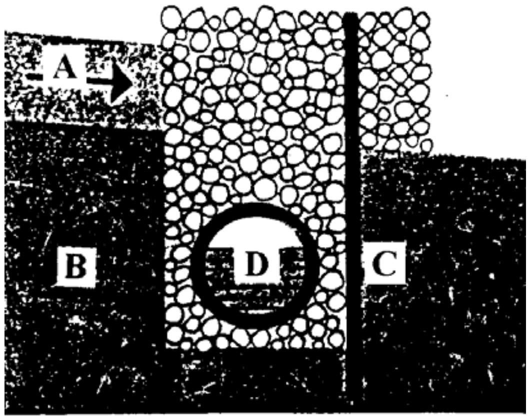

Fig. 1.14: Subterranean catchment (Overmann, 1971)

Tajamares

In widespread plains, e.g. in the interior part of large geological basins, the uppermost rock layers often consist of sediments such as clay, silt, and fine to middle sand. If in such geological positions sandy sediments are overlain by an impermeable clay layer which is partly interrupted, rainwater can seep down locally to the sand formation and form a fresh water lense. It is also possible to artificially convey surface water to such infiltration sites. The water can be extracted with a pump during dry seasons. This kind of RWH has been developed in the Chaco in South America and is called tajamares (Junker & von Hoyer, 1998).

Micro Catchments

The size of micro catchments, see Figs. 1.15 – 1.16, varies between 100 and 200 m^2. They are constructed on slopes with less than 10 % inclination and consist of circular, trapezoidal or rectangular bunds made of loamy soil (10 – 30 cm high) and rocks (up to about 1 m high). Runoff water enters the retention areas on the upper side, excess water can flow at both ends of the bund over a spillway (overflow) to the next, deeper located row of micro catchments.

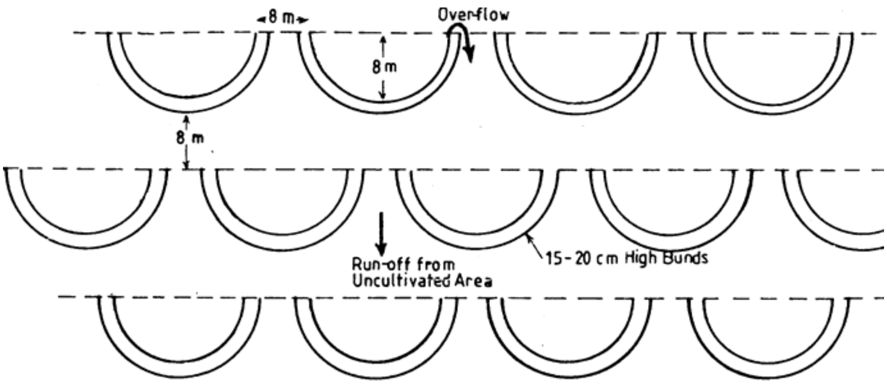

Fig. 1.15: Scheme of semi-circular catchments (Smith & Critchley, 1983)

Fig. 1.16: left: Micro catchments, Tunisia (Balke (1996); right: Micro catchments, Greece (Balke, 1999)

Micro catchments with bunds of loamy soil are also used to improve the water supply for trees in the landscape or along roads, see Fig. 1.17.

Fig. 1.17: Micro catchments for trees, Tunisia (Balke, 1993)

Field Irrigation

Generally, there are 3 possibilities to catch and use rain-water for the irrigation of crop land:

1. **in situ rainwater harvesting**: the rainwater is used on the same piece of land where it has been harvested,
2. **external rainwater harvesting**: catchment area and crop land (retention area) are separated from each other,
3. **protective rainwater harvesting**: between catchment area and crop land a water storage facility is interposed; with such arrangement the irrigation can be adjusted to the weather conditions and the demand of the plants.

Planting pits are small holes of 10 – 30 cm depth dug into the soil in order to retain rainfall and surface runoff. In order to increase the fertility organic matter (mulch, manure, etc.) should be placed in the pits. One crop can be planted in each pit. Collection of rainwater and cultivation of plants is done at the same place. Planting pits are one of the simplest and oldest RWH methods.

For **field irrigation** in flat areas, see Fig. 1.18, loamy material is heaped up in lines so that rainwater can flow from the collector areas (catchments) into the cultivated areas. The collector areas are normally larger than the cultivated areas.

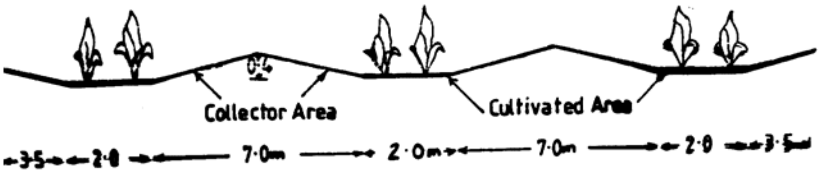

Fig. 1.18: Alternating collector areas and cultivated areas (Smith & Critchley, 1983)

Generally, the catchment must be large if the rainfall is small and erratic, evaporation losses are high and the water demand of the cultivated plants is high. In order to support a fast infiltration of water in the cultivated area the soil should be cautiously loosened with special equipment (conservation agriculture).

On gentle slopes, see Fig. 1.19, small bench terraces can be built to carry cultivated crops, which are supplied with water from the run-off areas (catchment). It has to be taken into consideration that the steeper the slope the higher the risks of erosion damages will be.

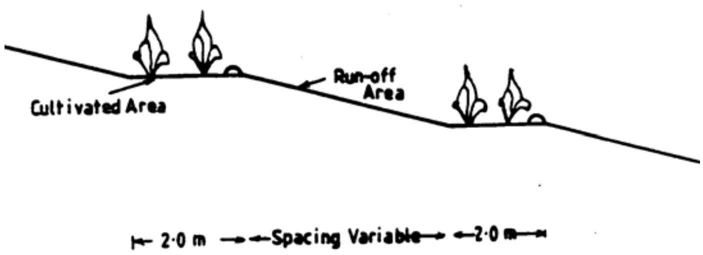

Fig. 1.19: Bench terraces (Smith & Critchley, 1983)

Depending on the morphology and the expected rainfall pattern various arrangements for field irrigation are possible: cultivable field segments are delimited by low ridges (bunds) situated along the contour lines, or arranged in squares or rhomboids, see Fig. 1.20. Spillways must guarantee that excess water can flow to the next deeper situated field. Suspensions and fine grained particles, carried away by runoff water, are deposited before the bunds and supplement the soil cover – and the possibility for cultivation – in the course of time.

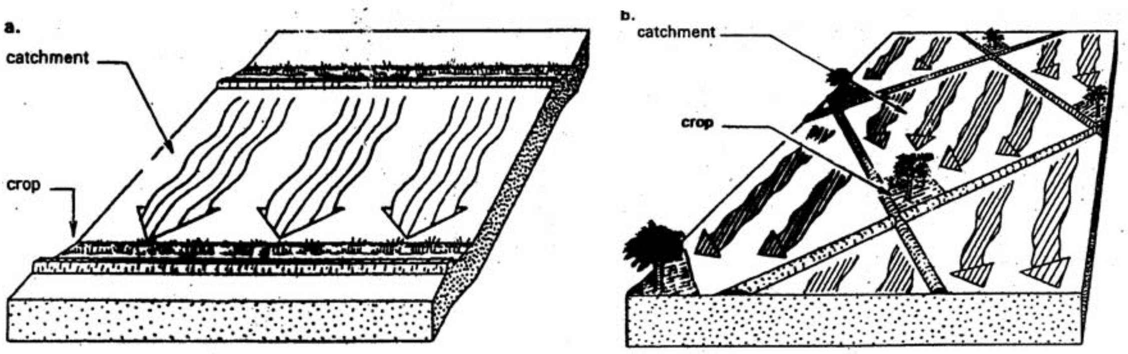

Fig. 1.20: Strip cultivation and square or rhomboidal arrangement of irrigation sections (Pacey & Cullis, 1986)

Macro catchments are mostly built on widespread slopes or in broad river valleys with more than 10 % inclination. The bunds, made of loamy material, can be strengthened by rocks or plants, e.g. cactuses. Areas with widespread outcrops of more or less impermeable hard rocks such as granite, gneiss, or compact basalt, limestone or sandstone are especially suitable as water catchments. The cultivated areas can be positioned in depressions that are filled with soil or at the foot of hills, see Figs. 1.21 – 1.22.

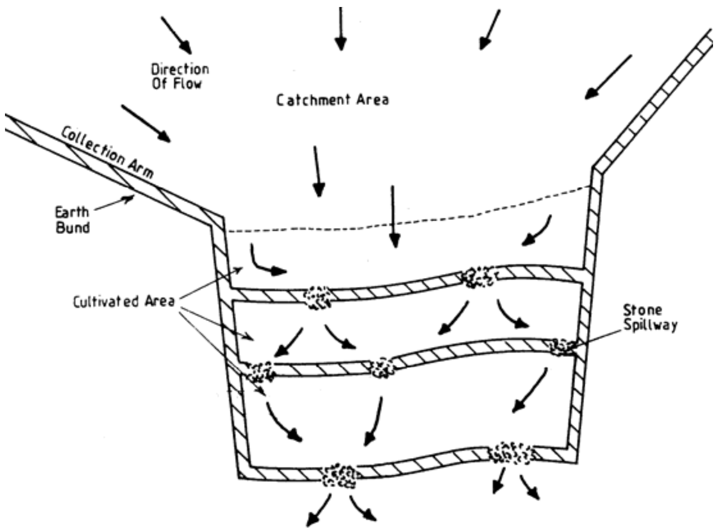

Fig. 1.21: Macro catchment area and crop fields, Kenya (Charnock, 1985)


Fig. 1.22: left: Macro catchments, Tunisia (Balke, 2002), right: Macro catchments, Yemen (Balke 1987)

Another possibility to handle harvested rainwater is to collect it on a prepared catchment, store it in a tank or cistern, and use it for irrigation during periods of demand, see Fig. 1.23. In such cases the **graded strip catchment** area should be less permeable and the water should be conveyed very quickly through run-off ditches and drains to the storage tank or cistern.

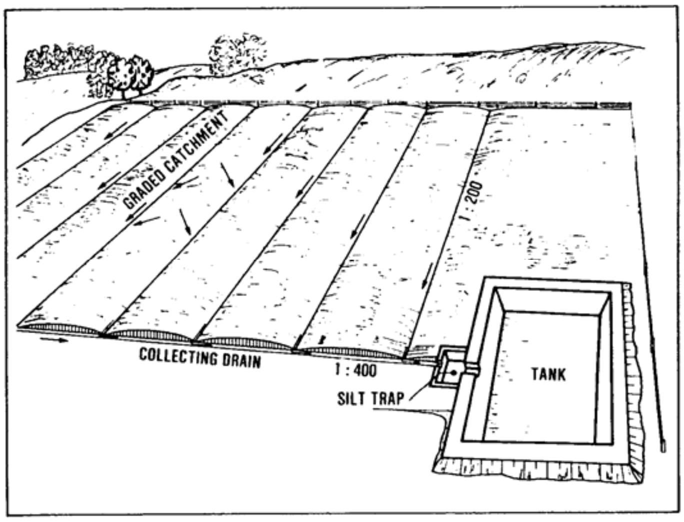

Fig 1.23: Graded strip catchment (Hofkes, 1983)

Roads, foot-paths and paved surfaces can be used as catchment areas if they are not heavily polluted.

Drip Irrigation systems for small scale farming are applied, e.g., in Brazil (Prinz, 2007).

A **clay pot drip irrigation** system consists of clay pots which are permeable for water and arranged in a series of several pots of ca. 30 cm diameter and 50 cm height (10 to 12 liters volume), dug in the uppermost soil layer. A plastic pipe delivers the irrigation water from a storage tank.

Bucket drip irrigation uses one big or some smaller buckets placed on an elevated position (ca. 1.00 to 1.20 m above ground). The water-filled bucket is connected with a plastic hose with tiny holes located directly at each plant.

A special aspect is the influence of RWH on the CO_2 balance and the **climate change**. An increase of cultivated areas and plant production by RWH technologies binds CO_2 and reduces its thermal influence in the atmosphere.

Fog and Dew Harvesting

On the windward slope of mountains, situated near the sea, air of high humidity arriving from the seaside is forced to rise up with the effect that clouds or fog (camanchacas in Chile) are formed at altitudes of approximately 400 m to 1200 m. With the help of flat, rectangular nets of ultraviolet-resistant polypropylene mesh, placed 1.5 m above ground and perpendicular to the prevailing wind direction, condensed water drops can be collected. The small droplets join, form bigger drops and flow down into a collection pipe, see Fig. 1.24. Additionally, dew can be collected from the nets in the early morning hours.

The captured water is stored in small tanks and conducted to consumers via PVC-pipes. Dependent on the meteorological conditions and the topographical position a fog net delivers about 3,5 l/m^2.

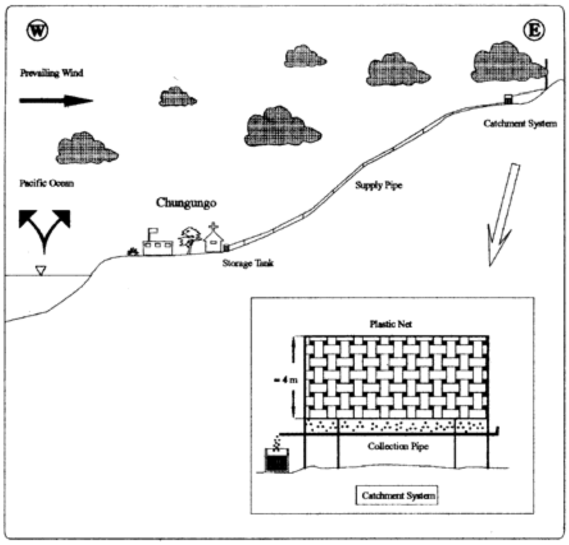

Fig. 1.24: Fog harvesting system

Such systems have been working in the Andes mountains for a number of years, supplying the small towns of Chungungo (about 500 people) and Paposo in Chile with drinking water, but they are also in use in Peru, Ecuador, Guatemala, Venezuela and Mexico as well as in Namibia, Yemen, Eritrea, Oman, South Africa, Israel and Nepal. There are several locations in South America, the western coast of South Africa, Arabia, and Europe where fog harvesting can be advantageous.

Involved Knowledge

The various RWH techniques were developed by ancient civilisations and have been practised for several thousands years (in Jordan 7,000 years B.C); they are still in use today. The techniques, adapted to the local conditions, are based on the experiences of previous generations. The installations are relative simple; they can be made by indigenous farmers using local and natural material. In many cases the agricultural standard is low and the crop yield limited. But the food production can be improved by combining the knowledge of local farmers with modern findings in meteorology, hydrology, agricultural sciences, and the application of modern equipment.

Key Actors

The installations for RWH are normally built and used by indigenous small scale farmers, but there are also projects run by user groups, water associations and governments.

Problems may arise if the population changes. There are areas where young people leave their homes and go to a larger community or to a town in order to find a job and to earn more money. Higher efficiency of farming with higher crop yield could make them stay at their place. On the other hand there are regions with rising population because of high birth rates; here the people need more crops and vegetables to avoid suffering from hunger.

International Cooperation

International cooperation in the fields of RWH involves financial promotion, the execution of special projects as well as scientific/practical information and training in the form of conferences, workshops and courses. Such projects are financed by the responsible government, supporting countries and/or by international organisations.

Some examples of international cooperation in the fields of RWH are cited in the following:
The UNDP funded the project "Research, Demonstration and Extension of Sustainable Agricultural Systems for Arid Areas in Northwest China", executed 1993 – 1997 by FAO in the Chinese Province of Gansu.
Canada financed 1989 – 2001 the "Hubei Dryland Project", China (Prinz, 2002).

The FAO provided technical support for the project "Integrated Desert Control and Sustainable Agriculture in Gansu Province", China.
The World Bank supported several projects concerning agriculture, irrigation and rural water supply in the Chinese provinces Gansu, Ningxia, Shaanxi, Sichuan, Xinjiang, and Yunnan.
The Asian Development Bank financed investigations on "Rural Water Supply Strategy" and "Water Conservancy" in Western China.
The FAO supported projects on water harvesting and conservation agriculture in some African countries such as Ghana, Kenya, Tanzania, Uganda, and Zambia. (FAO, Rome)
A cooperation between Germany and Tunisia for investigating the RWH techniques applied in Tunisia was carried out 2002 – 2003 by Tunisian and German institutes (Meinzinger, Prinz & Bellachheb 2004).

Several projects for the introduction and the improvement of RWH techniques have been run and are still going on worldwide. But there are many areas left where these techniques could be used or improved, especially in Africa and Asia. Considering the importance of food production further efforts are necessary. Compared with other measures for the development of developing and threshold countries such as the construction of big dams, water distribution channels, infrastructures, etc. the financial aid and the cooperation in the field of RWH is often insufficient and should be improved.

Potentials for Sustainability

Sustainable agriculture is the "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources " (Walsh, 1991).

RWH is a highly sustainable method to collect water because rainfall can not be over-used. Most of the natural material for RWH constructions such as rocks and soil is of local origin. Catchment areas and cultivated sectors cover fallow land that is normally not used or necessary for other purposes. If the constructions are built correctly according to the local conditions and always well maintained, and if adapted crops or trees are cultivated and conservation agriculture is practised RWH installations can be used for a nearly unlimited period of time.

The climate change is expected to cause an extension of regions affected by droughts. Therefore, existing RWH installations should be improved in order to increase their efficiency, and well adapted plants should be introduced wherever it is possible and advantageous. For the introduction of new RWH plants it is also necessary to take into consideration not only the local situation but also a watershed scale in order to avoid negative results concerning the natural conditions and the local population.

Key Restrictions/Unused Potentials

Within watersheds (with respect to a certain site, a watershed is the area from which all the surface water runs to that site) conflicts may arise concerning the water utilization between users located in upstream areas and those living downstream. Because nearly any water use leads to certain water losses, the quantity of water available for the users living in a downstream area is more or less reduced. Therefore, the introduction or enlargement of RWH plants needs information and cooperation with the people living at lower locations in order to avoid difficulties and struggle. If no people is affected – that may be the case in remote areas – the installation of more RWH plants results in an expansion of agricultural land and increases the productivity in the area.

Sometimes administrative problems may arise between governmental institutions. Micro dams, micro and macro catchments used for irrigation are constructions for agricultural activities and therefore under the control of the Ministry for Agriculture. But the Ministry of Water Resources is responsible for questions concerning the construction and operation of micro dam reservoirs.

Interrelation with Other Production Systems

There are some methods to produce usable water for agricultural purposes out of brackish, slightly polluted or hot water.

Brackish and slightly polluted water can be purified with the help of treatment methods such as reverse osmosis, ultrafiltration or evaporation. The needed electrical energy can be produced by diesel motors, photovoltaic power, or wind energy. Hot water delivered by deep borings must be cooled down with the help of cooling towers or cooling squares; the water losses are extremely high.

These methods require high-tech instruments, high power demand, high investment costs and trained personnel; therefore, they are much more costly than RWH technologies.

2 Current Relevance / Basic Data on Use

Global Area

The methods of RWH can be applied in every climatic zone but they are really important in regions without sufficient surface water or groundwater resources. Locally, air temperature and precipitation are influenced by the altitude and morphology of the land, by air and seawater currents. Particularly areas with arid and semi-arid climates, but also parts of sub-humid regions suffer for water scarcity. Such regions can be found in all continents except Antarctica, see Fig. 2.1.

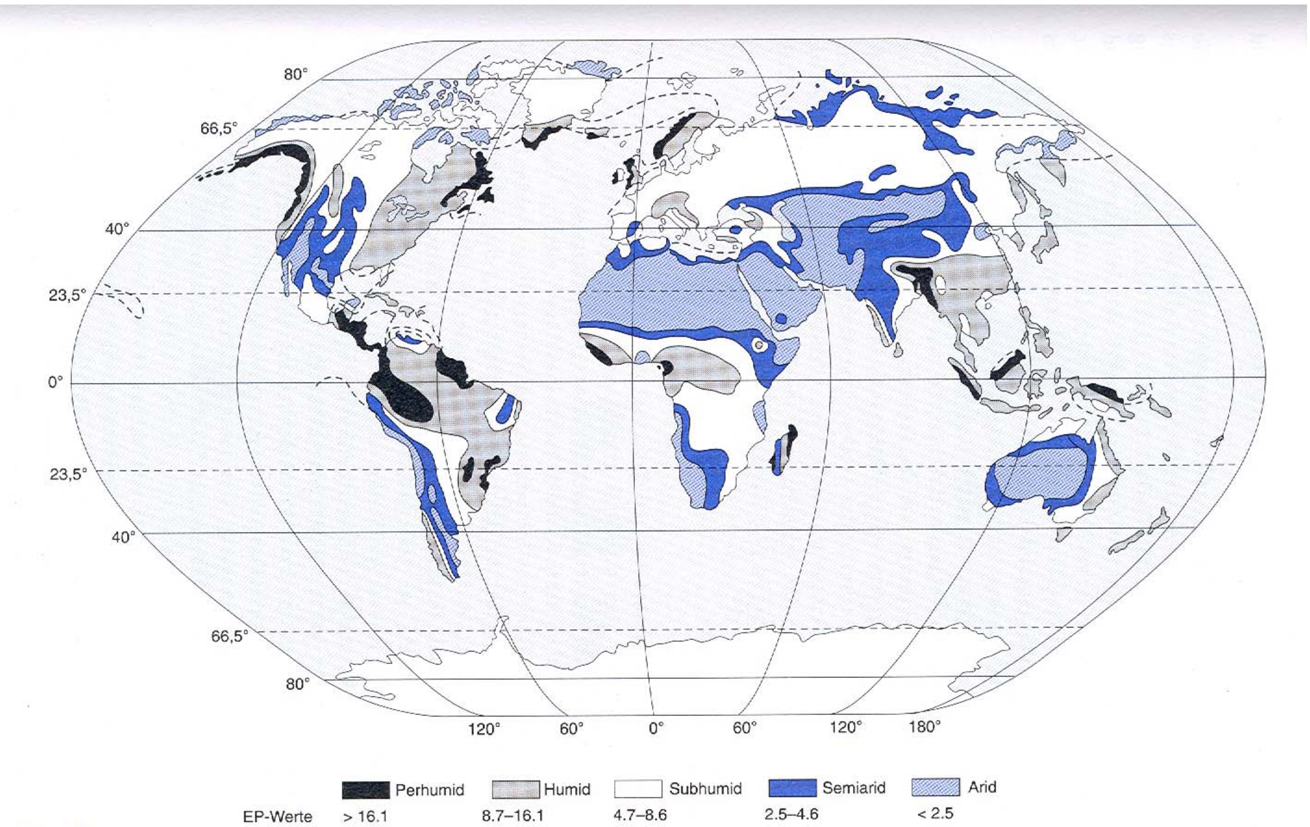

Abb. 113
Humidität und Aridität, ermittelt mit Hilfe der Schätzformel (9.6), vereinfacht (nach Blüthgen und Weischet, 1980, ergänzt).

Fig. 2.1: Climatic zones (Schönwiese, 2003)

Some industrialized countries are located in these climatic zones: the Southeast of USA (Arizona, New Mexico), Australia and Europe (especially Spain, Italy, and Greece, but even thenorth-eastern part of Germany).

It must be considered that the recent climate change will shift the climatic conditions on the globe, and many drought-prone areas are expected to be endangered even more in the future.

Area in Developing Countries

Most of the threshold countries and developing countries are affected by droughts: the northern part of Mexico, some regions in South America especially in the Andes Mountains, North and East Africa (Morocco, Algeria, Tunisia, Libya, Egypt, Mauritania, Mali, Niger, Chad, Sudan, Ethiopia, Kenya, Tanzania, etc.), the semi-deserts, savannas and steppes of Subsaharan Africa (Angola, Namibia, Botswana, South Africa), Middle and Near East, the Arabian Peninsula, widespread areas of Asia (Irak, Iran, Afghanistan, Pakistan, India, Bangladesh, Sri Lanka, China), and Central Asia (Kazakhstan, Uzbekistan, Tajikistan, Turkmenistan, Kyrgyzstan, Mongolia).

RWH is mostly used in African and Asian countries.

Micro catchments are used e.g. in Kenya, Niger, Tanzania, Tunisia (Meinzinger, F.; Prinz, D. & Bellachheb, CH. (2004). Infiltration trenches have been established e.g. in Ethiopia, Tunisia, Uganda. Strip cultivation systems and contour ridges have been developed e.g. in Botswana, Kenya and Zimbabwe. Pitting systems are applied e.g. in Burkina Faso, Tanzania, Tunisia, Uganda, and Zambia. FAO, the Food and Agriculture Organisation of the United Nations, Rome, initiated and supported several investigations on practised water harvesting and conservation agriculture in Kenya (Kaumbutho, Kienzle (ed.),

2007) and Uganda (Nyende, Nyakuni, Opio, Odogola, 2007) among other countries.

Other African countries where RWH methods are practised are Algeria, Ghana, Mali, Malawi, Mozambique, Namibia, Sierra Leone, South Africa, and Togo.

In Asia RWH is practised in Near East, especially in Israel, in Pakistan, Mongolia, etc. In China several RWH projects are running in the western and northern part of the country (Qi-jang Zhu, 1998; Prinz, 2002; SIWI, 2001) but also in semi-humid and humid areas with seasonal droughts in southern China (Zu et al., 1996).

In India there are projects to re-introduce old indigenous RWH techniques and to establish small scale RWH plants (Narain, 1998).

RWH activities can be found in South America as well, e.g. in Brazil (Prinz, 2007), Paraguay (Junker & von Hoyer, 1998) and northeast Argentine, as well as in Australia.

Distribution Climate Zones / Vegetation Zones

In deserts and semi-deserts natural vegetation does not exist at all or is very scarce. Rain-fed agriculture is not possible, but RWH can be practised successfully in regions with an annual precipitation of more than 150 mm in winter or 200 mm during summertime (Prinz et al.). In areas with lower precipitation rates rainfall is too irregular and the catchment areas and reservoirs or cisterns must be extremely large with the effect that the expenditures for the constructions become too high.

In semi-arid and semi-humid regions the natural vegetation of the steppes and savannas consists of grass and bushes, single or small groups of trees, and gallery forest along rivers.

Distribution Farm Types

Farmers whose water supply is based on RWH techniques usually live in small villages, in settlements of a few farmhouses or in a single family house, often far from urban areas. They produce fruits, crops or vegetables for their own consumption; if there is a surplus of foodstuff they sell it in order to earn some money.

RWH for agricultural purposes is especially important for small farming. Single families or a small group of farmers use some large or several small RWH-fed catchments, convey the water to several cultivated areas and/or into storage facilities.

3 Restricting Framing Conditions

Financial Resources / Financing / Poverty

The implementation or improvement of a RWH project must be affordable for all members of the group of users. In developing countries the financial resources of farmers, especially of small farmers, are very limited. Even the tools needed for the construction and maintenance of RWH installations are often not available. Construction material such as bricks, cement, pipes, plastics, containers, etc. can not be afforded. In addition, plant seeds and tree slips will be needed especially at the beginning of a RWH-fed cultivation of crops, vegetables or trees. In order to improve the situation it is necessary to run RWH development projects including financial aid from governmental or international sources, probably combined with mini-credits for the farmers. Nevertheless, it must be agreed that the procurement of water by RWH technologies is much cheaper than other methods using wells, desalination plants, or water pipelines.

Land Rights, Land Ownership

Before the initiation of a new RWH project it must be found out what land rights and water laws have to be respected: indigenous laws, religious commandments, laws derived from western laws, or no special laws.

The land ownership is a deciding factor in the installation and operation of RWH systems. Normally, the state, the community or one or more private persons are the land owners. If there are several land owners an agreement must be worked out among the partners about the general scheme and the details of the project, and concerning their rights, financial contributions and partition in a financial surplus. A user´s water association can be founded as a frame for the cooperation. Several families, ethnic, self-help or religious groups can establish a co-operative as well. If the land belongs to the government or to the community the project must be explained and discussed with the administrations involved in order to get the necessary legal permits.

Considerations and resolutions about land rights, ownerships, RWH technologies, management, and the practical work must respect cultural, social and socio-economic backgrounds.

Infrastructure (as Transport, Electricity etc.)

Often, the infrastructure (streets, railway, supply with water and electricity) is on a very low level or completely lacking in poor and remote areas where often life depends on RWH agriculture. If a surplus of crop yield can be produced, the farmers need a possibility to bring their fruits or crops to a market place in the surroundings; a local solution for the transportation problem must be considered during the planning phase for RWH projects.

Political System, Corruption

In spite of its potential, RWH has not received adequate interest among policy makers, planners and water project managers (Mbugua, 1998). Therefore, political forces must be convinced that RWH techniques are not primitive methods but very important for the food production especially for small scale farmers in dry and poor regions. It must be taken into consideration that corruption may endanger RWH projects.

4 (Technical) Potentials for Improvements (Available and Emerging Technologies for Improved Productivity)

Addressed Problem

RWH installations – the way they are found nowadays - are often not as efficient as they could be, in fact in many cases they are far below their potential (Qijang, 1998). Often the arrangement of catchments and cultivated areas and constructional details are insufficient and cisterns lose too much water by seepage and evaporation. In order to secure the water supply in dry regions, to increase the productivity of arable and grazing land as well as the agricultural yield, the methods of RWH need to be improved. This includes not only constructional and technical improvements but also agricultural measures to bring about maximally favourable conditions for the growth of plants and reduce their risk of drying up.

The combination of traditional techniques, based on the experiences of former generations, with recent scientific knowledge in climatic and hydrologic conditions, constructional possibilities and the latest findings in agriculture can improve the efficiency of RWH techniques to a great extent.

Another aspect concerns the management of the scarce water resources in order to supply as many consumers as possible and to avoid difficulties between them. If there are several RWH plants in an area, located one upon the other at different levels, it must be guaranteed that cultivated areas located at lower levels also receive enough water. This necessitates, e.g., an optimal positioning of the spillways of micro-dams and micro- and macro-catchments, an efficient use of the available water quantity and an avoidance of water wasting. It is very important to have trained people carry out sufficient and continuous maintenance .

Some RWH systems have fallen in disuse either due to structural deficiencies, insufficient construction, lacking maintenance or wrong cultivation. In such cases, repair, re-introduction, adaptation of recent technical and agricultural possibilities and improved efficiency are necessary. Additionally, information and training programmes shall be offered for the farmers.

Above all, small scale farmers are interested in low-cost projects with fast pay-off of investments, located close to their homesteads.

Technical / Organisational Solution (Changes in Production System)

The implementation and improvement of RWH systems must be based on the identification of specific geographical units with similar characteristic patterns, the formulation of water management strategies, and finally on the self-reliance of the users.

In developing countries the construction of bunds, dams, spillways, etc. is mostly executed by hand with the help of simple tools. The small scale farming is at a very low level of mechanisation, the most widespread method of field cultivation is hand-hoeing.

Conveyance systems between catchment areas and cultivated areas or the storage equipment can sometimes be improved with the help of industrially produced pipes and attachments. If the water must be filtered sieves with filter sand of appropriate grain size shall be used.

The right distance between the base of the spillway and the soil surface in the retention area of micro- and macro dams shall regulate the water flow in the retention area. If the distance is too small the water flows fast and the infiltration into the soil will be small, suspended material carried along with the water can not precipitate. If the distance is too high ponding is caused, the plants are waterlogged, a lot of the water evaporates and probably leaves a layer of salt.

In general, an optimal design of the RWH installations including the selection of the type, arrangement and size of the water catchments and retention areas as well as a good water management must guarantee that the farmers and users situated within a hydrologic catchment (watershed, i.e. the entire area delivering the rainwater and runoff for the man-made RWH constructions) can be supplied with sufficient water. Moreover, the improvement of agronomic practices, including the use of appropriate plant material, plant protection measures and soil fertility management is necessary. This can be achieved by the application of the techniques of conservation farming, see section 1, Key Elements.

Important Differentiations for Global Regions, Major Cultivation Conditions and Farming Systems

RWH is practised in America, Africa, Asia, Australia and Europe. Various kinds of RWH techniques as described in section 1 have been developed due to the different natural conditions and human demands and habits. Some of them are more or less similar, some are unique. It may be advantageous to transfer techniques and experiences – perhaps with certain adaptations - from one place to another if the conditions are more or less similar. In this respect, the transfer of information about

- the various kinds of RWH techniques and their special applications,
- the various constructions of cisterns and reservoirs,
- experiences with special techniques e.g. the tajamares, the clay pot and bucket drip irrigation methods,
- possible combinations of harvesting methods for rainwater and surface water,
- productive plants and crop rotation practices

can lead to optimized solutions.

Achievable Effects (Higher Yields, Higher Productivity, Lower Vulnerability, Higher Income)

In many regions the application of RWH techniques can be introduced or intensified. As a result more water will be available for domestic use, for crop cultivation and cattle feeding. Additionally, it has to be examined how agricultural productivity can be improved by fertilizing without or with only a very limited quantity of chemical agents.

With such measures the size of the productive areas in a region can be enlarged and the productivity improved. Higher crop yields lead to higher income and a better living standard of the farmers. It will also be possible to increase – to a certain extent - the population density.

Necessary Steps (Preconditions for Introduction) as Technology Development and Adaptation, Extension Service, Financing, etc.

The introduction or improvement of RWH techniques can not only be practised by external experts from the government or international organisations. The involvement of the local farmers and/or community groups is an important precondition for getting successful results. They must be informed, invited to cooperate in planning and fieldwork, and trained in managing.

The design of the farming system, the working force and the financial capabilities of the farmers, their priorities, cultural behaviour and religious belief, their experience and knowledge about RWH methods, the land tenure, property rights and water laws have to be taken into consideration.

The constructional measures (number, position and kind of constructions) for the improvement of RWH in an area and the agricultural decisions (choice of trees, crops, vegetables) must be designed and practised by a team of external and local experts, covering the fields of hydrogeology, civil engineering and agriculture, working together with the local farmers.

Relevance / Availability for Small Scale Farmers

RWH techniques are especially interesting for small scale farmers because they can make the constructions and most of the needed material is delivered from the natural surroundings free of charge. If they get information and support from external experts the construction and use of the installations can improve their living standard and deliver food for other people, too.

5 Effects for Small Scale Farmers

Chances

RWH technologies are simple to install, to operate and to maintain. The provision of adequate water resources enables small scale farmers to increase their harvest. If they produce more crops and fruits than they need for themselves, the surplus can be sold. This reduces poverty, improves the health security and makes their life economically more stable. The application of RWH methods usually reduces the time to fetch water and the dependency on water allocation. The increase of crop production and income also reduces intentions to migrate to urban areas.

Higher productivity can additionally be achieved by using fertilizers, preferably natural humic matter. The number of plants in a cultivated area should meet the most efficient scale. Higher income enables the investment in resource conservation measures such as soil conservation, enhanced irrigation techniques (e.g. drip irrigation), and possibly reforestation. Erosion and desertification in the area can be diminished as well.

Because of the population growth in developing countries more and more people, mostly the poorest, are forced to go to poorly populated dry areas. An intensification of RWH technologies can help to overcome their poverty.

Compared to deep wells delivering groundwater, RWH systems are much more cost effective. The ecological consequences of the enlargement of areas carrying vegetation supplied by RWH methods typically have positive effects on the surroundings.

Risks

A disadvantage of RWH technologies is the uncertainty of rainfall in arid and semi-arid regions. There is no guarantee that the water availability fits the growth period of the plants. But based on long-term experiences and modern knowledge it is normally possible to find satisfying and sustainable solutions such as the choice of appropriate plants and the construction of cisterns of sufficient sizes.

Water conflicts may arise between people living or acting upstream and downstream in a watershed. There may be a reduction of runoff that originally feeds farmland, rivers, or recharges shallow groundwater at downstream positions.

Sometimes it may be difficult to implement or enlarge RWH structures because the people living around do not accept the project, the political agreement is difficult to obtain, the management skills are insufficient, or the financial means are not available.

It may also be difficult to get the material needed for the construction of RWH structures or to find customers to buy the surplus yield because no local market exists in the near surroundings.

6. Favourable Settings for the Promotion and Sustainability of the Agricultural Production System (Summary of Results)

The availability of water is the precondition for human life and agriculture. Agriculture has been identified as a priority sector in reducing poverty. In dry regions with irregular and scarce precipitation, ephemeral rivers and no shallow groundwater of appropriate quality the local water demand for small scale farming can be balanced by rainwater harvesting (RWH).

The RWH technologies are decentralised water distribution systems including the collection, filtration and storage of local rainwater and surface runoff. Corresponding to the local conditions (climate, morphology, soil, etc.) many different techniques can be applied. RWH methods make it possible to supply human beings and cattle with water, to enlarge the productive land, to increase the crop yield, and finally, to reduce the rural migration to urban areas. Moreover, erosion and desertification can be diminished. Under appropriate circumstances RWH delivers water for reforestation and groundwater recharge as well.

An important RWH method that can be applied in nearly every kind of landscape is the collection of water in cisterns. In mountainous regions rain and surface runoff can be collected in the retention areas before micro dams, in infiltration trenches and hill catchments. In flat regions subterranean embankments and catchments, micro- and macro catchments, field irrigation, and graded strip catchments are often in use. Clay pot irrigation and bucket drip irrigation should be introduced on a larger scale in African and Asian countries. A special technique, applied in high mountains near the sea, is fog harvesting.

RWH installations are relative simple, but they can be practised with local and natural material by the indigenous farmers. The agricultural standard is low and the crop yield limited but it can be improved by using the advice of external experts.

RWH technologies are simple to install, to operate and to maintain. They are very sustainable, particularly in combination with conservation agriculture. In certain cases RWH methods can also be used for the restoration of degraded land. Most of the natural material for RWH constructions (rocks, soil) is of local origin. In many cases, catchment areas and cultivated sectors cover fallow land.

Compared with other methods for gaining usable water (wells or the desalination of salty or polluted water by reverse osmosis, ultra-filtration or evaporation) RWH techniques are quite cheap and easy to maintain. The construction of a well is expensive, especially if the well must be sunk into deeper aquifers, a boring company must be charged and construction material such as bricks, pumps and pipes are needed. The methods of water desalination require sophisticated equipment, energy to drive the process, trained personnel, and moreover, the remnants such as brine or salt must be removed. For the preparation of a RWH catchment area local material (rocks, loam) can be used free of cost, the work can be done by the farmers themselves.

The methods of RWH can be applied in every climatic zone with water deficiency. It is especially important for threshold countries and developing countries in the south-west of North America, some regions in South America, in large areas of North Africa, Sub-Sahara and southern Africa, Middle and Near East, the Arabian Peninsula, and widespread areas of Asia.

RWH methods are especially used by small scale farmers whose financial means are very limited. In order to improve their situation it is necessary to run RWH development projects including financial aid from governmental or international sources, perhaps combined with mini-credits for the farmers.

The introduction or improvement of RWH techniques must be done in cooperation of external experts from international organisations with competent experts of the concerned country and the local farmers or community groups.

Each RWH project has to consider and to respect ownerships, land rights and water laws (indigenous laws, religious commandments, laws derived from western laws), cultural, social and socio-economic backgrounds. A water association can be founded by the users as a frame for the cooperation. Some families, ethnic, self-help or religious groups can establish a co-operative as well.

In many cases, the infrastructure is on a very low level in poor and remote areas where often life depends on RWH agriculture. If it can be expected that a surplus of crop yield can be sold it must be considered that the farmers need access to a market place in the surroundings.

Sometimes, political forces must be convinced that RWH techniques are not primitive methods but very important for the food production especially in dry and poor regions.

Nowadays, RWH installations are often not as efficient as they could be, sometimes far below their potential, and they need to be improved. In such cases, repair, re-introduction, adaptation to the present situation and improvement in better efficiency is necessary. It is important to consider the management of the scarce water resources in order to supply as many consumers as possible and to avoid difficulties between them. In order to avoid difficulties the farmers should undergo an information and training programme.

RWH technologies are sustainable and environmentally friendly. River water and groundwater are not consumed. According to the recommendations of conservation agriculture the tillage is practised in a careful way in order to keep a favourable soil structure. For soil fertilizing plant remnants or in limited cases, very small quantities of chemicals shall be applied. After the installation of RWH plants the additional vegetation consumes CO_2. Moreover, erosion is inhibited or stopped. Difficulties may arise if in a watershed RWH plants utilize water in the upstream area causing a reduction of available water for the farmers living in downstream areas. In such cases the distribution problems must be solved by a just water management.

As a consequence of the ongoing climate change it must be expected that regions being affected at present by droughts will extend in the future. The negative consequences of a reduced agricultural yield, caused by longer dry periods, could be diminished by the introduction and adaption of RWH techniques which are nowadays in use in regions that are already more dry. If the area cultivated by RWH technologies can be enlarged worldwide the additional vegetation will bind a certain amount of CO_2.

7. Areas of Action / Options for Action

In many cases the agricultural standard of RWH techniques is low, the installations are often not as efficient as they could be, in many cases they are far below their potential. In order to overcome this problem an exchange of experiences concerning constructions, tillage, cultivated plants, etc. between farmers from various geographical areas should be launched.

Another necessity is the optimization of RWH techniques with the help of computer models. By varying the involved parameters such a research project could work out the most efficient constructions and arrangements of RWH installations.

Practical projects for the introduction or the improvement of RWH technologies for increased food production in developing countries should be executed in a cooperation of external experts with internal experts from the respective country and the concerned farmers in the area under development.

The external experts shall be experienced in the various RWH techniques, the internal experts shall know the time-tested and reliable RWH techniques that are utilized in their country – sometimes it may be necessary to start the project with a training for the internal experts -, and the local farmers and communities shall be informed about the project, its chances and consequences, and be included in the planning; they shall also take part in the practical fieldwork.

A detailed description of the area under investigation delivers information on the suitable RWH technique, and it enables the decision whether new RWH installations shall be constructed or the existent RWH plants are to be improved or completed.

After the construction of the RWH installations the small scale farmers need to receive detailed information about the soil and the kind of farming: how to treat the soil and preserve its fertility, what kind of plants can be cultivated, what maintenance is necessary, etc. Legal questions must be clarified as well as infrastructural problems such as the access to local markets.

After a certain period of time the success of the RWH development project should be examined by an inspection.

References

Baudron, F., Mwanza, M., Triomphe, B., Bwalya, M. (2007): Conservation agriculture in Zambia: a case study of Southern Province. 57 p., FAO, Rome

Baumgartner, A. & Liebscher, H.-J. (1996): Lehrbuch der Hydrologie, Bd. 1, Allgemeine Hydrologie, Quantitative Hydrologie, 694 S., Berlin,Stuttgart

Boahen, Ph. et al. (2007): Conservation agriculture as practised in Ghana. 28 p., FAO, Rome

Boers, Th.M. (1997): Rainwater Harvesting in Arid and Semi-Arid Zones. 127 p., Int.Inst. for Land Reclamation and Improvement, Wageningen

Ehlin, U. et al. (1998): Water Harvesting. SIWI Paper 2, Stockholm

Falkenmark, M. & Rockström, J. 1993, in SIWI Report 11, (2001): Water Harvesting for Upgrading of Rainfed Agriculture. Stockholm

Falkenmark, M., Fox, O., Gunn, P. & Rockström, J. (2001): Water Harvesting for Upgrading of Rainfed Agriculture. SIWI Report 11, Stockholm

FAO Food and Agriculture Organisation of the United Nations (2008), Rome

Frasier, G. & Myers, L. (1983): Handbook of Water Harvesting. Washington D.C.: U.S. Dept. of Agriculture, Agricultural Research Service

Gould, J. & Nissen-Peterson, E. (1999): Rainwater Catchment Systems. UK: Intermediate Technology Publications

Hatibu, N. & Mahoo, H. (2000): Planning Handbook for Rainwater Harvesting in Tanzania. RELMA technical Handbook, Sida/RELMA,. Nairobi

Hemenway, T. (2000): Gaia’s Garden: A Guide to Home-Scale Permaculture. Vermont: Chelsea Green Publishing Company

Hofkes, E.H. (Ed.) (1983): Small Community Water Supplies - Technology of Small Water Supply Systems in Developing Countries. Chichester

Junker, M. & von Hoyer, M. (1998): Verbesserung der Trinkwasserversorgung für die armen Bevölkerungsgruppen im Chaco von Paraguay. Z.angew.Geol., 44, p. 100 – 107, 6 fig., Hannover

Kaumbutho, P., Kienzle, J. (ed.), 2007): Conservation agriculture as practised in Kenya. 150 p., FAO, Rome

Lauer, W. & Rafiqpoor, M.D. (2002): Die Klimate der Erde. 271 p., 35 fig., 16 tab., Stuttgart

Lowes, P. (1987). "The Water Decade: Half Time", in John Pickford (ed.): Developing World Water. London: Grosvenor Press International, pp 16-17.

Ludwig, A. (1994): Create an Oasis With Greywater: Choosing, Building, and Using Greywater Systems. California: Oasis Design

Mamou (1981): unpublished dissertation, Institut de Géologie, Université de Tunis, Tunisia

Meinzinger, F.; Prinz, D. & Bellachheb, CH. (2004): Analysis of Traditional Rainwater Harvesting Techniques in South Tunisia. In: 4th IWA World Water Congress, 19.-24.09.2004, Marrakech

Mishra, A. (2006): Water Harvesting – Ecological and Economic Appraisal. Authorspress Global Network, Delhi-110092, ISBN 81-7273-307-0

Mbugua, J. (1998): Rainwater Harvesting and Powerty Alleviation, Laikipia Experience. SIWI paper 2, p. 44 – 47, Stockholm

Narain, S. (1998): Using Rainwater as the Key for Ecological and Economic Growth; Regenerating Village Natural Resources with People´s Participation. SIWI paper 2, p. 29 – 34, Stockholm

Nyende, P., Nyakuni, A., Opio, J.P., Odogola, W. (2007): Conservation agricolture: a Uganda case study. 59 p., FAO, Rome

Overmann, M.(1971): Wasser. 192 S. dva-Verlag, Stuttgart

Pacey, A. & Cullis, A. (1986): Rainwater Harvesting – The Collection of Rainfall and Runoff in Rural Areas. UK: Intermediate Technology Publications, London

Prinz, D. (2002): Report of the FAO multidisciplinary Field Programme Review and Development Mission to Western China. Karlsruhe

Prinz, D. (2007): Water Conservation in Agriculture WACO. IWG, Karlsruhe University, Karlsruhe

Prinz, D. et al.: Water Harvesting for Crop Production. FAO Training Course, Rome

Qijang, Z. (1998): Rainwater Utilization as Sustainable Development of Water Resources in China. SIWI paper 2, p. 19 – 28, Stockholm

Schleichert, U. (1975): Schwermetallgehalte der Schwebstoffe des Rheins bei Koblenz im Jahresablauf.- Dt.Gewässerkdl.Mitt. 19, 150-157

Schönwiese, Chr.-D. (2003): Klimatologie. 440 p., 163 fig., 31 tab., Stuttgart

Shetto, R. & Owenya, M. (ed.) (2007): Conservation agriculture as practised in Tanzania. 183 p., FAO, Rome

Standish-Lee, P., Lecina, K. & Loboschefsky, E. (2006): Preparino for climate change in the western US. P. 20 – 22, Water21, London

Tippner, M. et al. (1978): Schwebstoffe und Schlammablagerungen in Bundeswasserstraßen. Jahresbericht 1977 der BfG, Koblenz

Todd, D.K. (1980): Groundwater hydrology. 535 p., New York

Zu, Z. et al. (1996): Making full use of rainfall-runoff in an effective way to develop irrigation agriculture in areas lacking of water. Proceedings of 1st NACORU, Lanzhou