Keynote Lecture

THE ROLE OF WATER HARVESTING IN ALLEVIATING WATER SCARCITY IN ARID AREAS

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Abstract: In many arid and semiarid areas, pumped ground water and the water from streams, rivers and reservoirs is no longer sufficient to cover the ever increasing water demand. Therefore new interest in ‘marginal’ water resources like rain- and floodwater harvesting came up in recent decades.

Traditional water harvesting techniques have been practised in many dry areas since long. Some prominent examples are rain water harvesting, floodwater harvesting, fog & dew harvesting, and the use of quanats, underground dams and special wells, called groundwater harvesting

If these small scale irrigation methods can be revived and improved, they will provide excellent opportunities to ease future water scarcity in arid and semi-arid areas of the world.

Keywords: rain water harvesting, floodwater harvesting, fog & dew harvesting, quanats, underground dams

Introduction

Water scarcity will be one of the major threats to humankind during this century (Prinz 2000). As the available water resources taken from streams, rivers and ground water will not be sufficient in most dry areas of the world to cover the needs of agriculture and urban areas, we have to reassess the value of certain traditional irrigation methods, to find out their value to ease future water scarcity (Prinz and Singh 2000)**.**. Methods are covered in this paper, which were developed in areas without permanent rivers, where people had to rely on rainfall, fog, dew or subsurface flow of water. Emphasis is given to methods applied in agriculture. Nowadays, these methods, coupled with water saving techniques, modern hydrological tools and remote sensing, may supplement the other sources of water and help to secure future water supply.

Since ancient times, farmers and herders in dry areas of the tropics and subtropics have, under widely varying ecological conditions, attempted to ‘harvest’ water to secure or increase agricultural production. A wide range of indigenous irrigation techniques can be found in areas between 100 and 1500 mm annual precipitation and with population densities varying from 10-500 persons / km^2.

These traditional methods played a much greater role in the past and were the backbone of ancient civilisations in arid and semi-arid areas around the world (Agarwal & Narain 1997, Prinz 1996).

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The technical means of the 20th century in lifting groundwater or establishing large canal systems even with inter-basin water transfer, coupled with a distinct government policy favouring ‘modern’ water supply and distribution techniques, brought about a decline in traditional systems.

General Overview

This paper will cover some ‘non-classical’ irrigation methods, giving an overview over traditional methods which have proven (often over millennia) to work efficiently, which can be applied without large investments and which offer good prospects for future development.
The traditional methods to ease water scarcity in dry areas, which are explained here, can be subdivided

- according to the source of water used (rainfall, fog, dew, groundwater) and
- according to the kind of storage (above-ground, underground) (Fig. 1, Tab. 1).

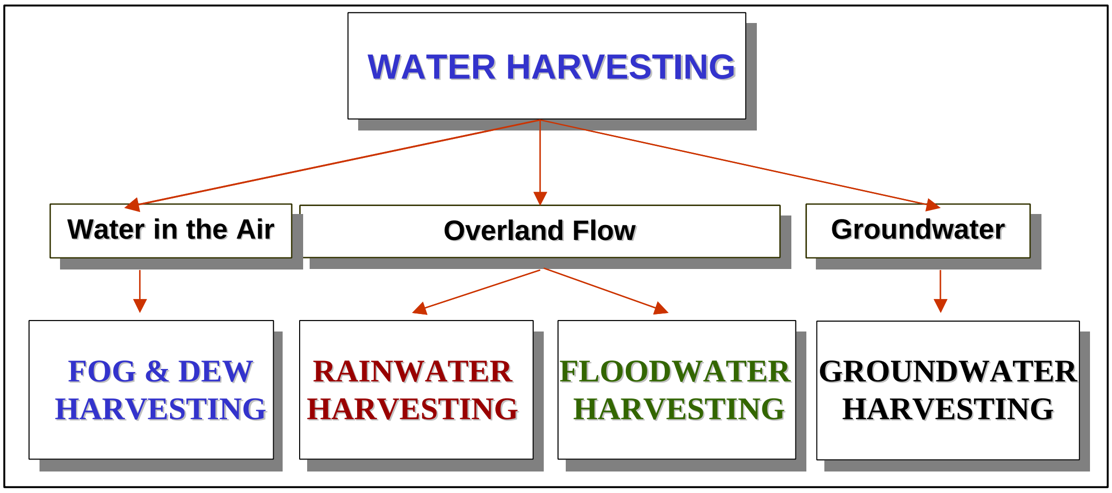


Fig. 1: Water Harvesting methods

Water Harvesting Methods

Rainwater and floodwater harvesting

The conventional irrigation methods use the rainfall after it has infiltrated into the ground, using underground water or the water of permanent streams and rivers. The methods, which are described in this chapter, collect the rainfall before it enters the soil, i. e. as surface runoff / overland flow.
Rainfall is collected, concentrated and used for the irrigation of crops, pastures, trees, for livestock consumption and household purposes. Therefore each system requires a:

- "runoff area" (catchment) with a sufficiently high run-off coefficient and a
- "run-on" area for utilisation and / or storage of the accumulated water.

Major types
According to the size of the catchment and the ratio between the size of the catchment and that of the cropping area, two major types of water harvesting (WH) for agricultural purposes are distinguished: Rainwater Harvesting and Floodwater Harvesting (Fig. 2).

The higher the aridity of an area, the larger is the required catchment area in relation to the cropping area for the same water yield. Water collected from roofs and paved courtyards is mainly used for domestic purposes, very rarely for garden crops, too.

WH Group	**RAINWATER HARVESTING**			**FLOODWATER HARVESTING**		**GROUNDWATER HARVESTING**		
WH Type	Roof and Court-yard WH	Micro-Catch-ment WH	Macro-Catchment WH	FWH Wihin the Streambed	Flood Water Diversion	Qanat Systems	Ground-water Dams	Special Wells
Techniques	Treated Surfaces e.g. Sealed Paved, Compacted, Smoothened Surfaces	Contour Bunds Interrow-WH	Hillside Conduit Systems	Jessour Type	Wild Flooding	Short Qanats	Sand Storage Dams	Horizontal Wells
		Negarin / Meskat Type WH Pitting Techniques	Semi-circular Hoops	Liman Terraces	Water Dispersion	Medium Sized Qanats Long Distance Qanats	Sub-surface Dams	Artesian Wells
			Cultivated Reservoirs/ Tanks	Percolation Dams	Water Distribution			
		Eyebrow T.	Stone Dams					
		Vallerani Type WH	Liman Terraces					
		Semi-circular bunds	Jessour Macro-Catchments					
		Contour Bench Terraces						
Kind of Storage	Cisterns, Ponds, Jars,Tanks	Soil Profile (Ponds)	Soil Profile, Cisterns, Ponds, Reservoirs	Soil Profile Reservoirs	Ponds	Ponds	Substrate Profile	Soil Profile, Ponds
Aquifer Recharge	None	Very Limited	Limited	Strong	Very Strong	Limited	Medium	Medium

Tab. 1: Groups, types and subtypes of overland flow and groundwater harvesting for agriculture and forestry

There are two major groups of techniques of **Rainwater Harvesting** (Fig. 2) :

- **Microcatchment water harvesting** is a method of collecting surface runoff (sheet or rill flow) from a small catchment area and storing it in the root zone of an adjacent infiltration basin. The basin is planted with a single tree or bush or with annual crops (Prinz 2001).
- **Macrocatchment water harvesting** is also called "water harvesting from long slopes" or "harvesting from external catchment systems" (Pacey & Cullis 1988). In this case, the runoff from hillslope catchments is conveyed to the cropping area, which is located below the hill foot on flat terrain.

Fig 2: Examples of Rainwater Harvesting techniques with general features. Microcatchment: Meskat system from Tunisia (Source: El Amami, 1983); Macrocatchment technique: Hillside Conduit technique (Source:. Prinz 1998); Source of text: Prinz 1998

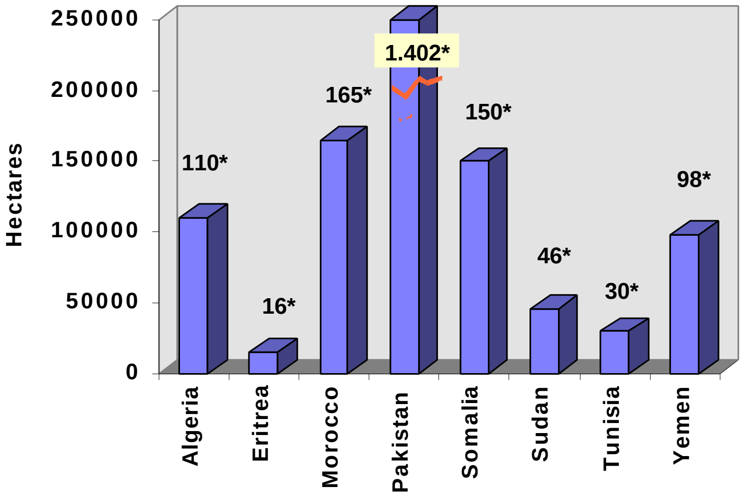
Floodwater Harvesting, also called ‘Large catchment water harvesting’ or ‘spate irrigation’ comprises two forms:

- In case of "**Floodwater harvesting within the stream bed**" the water flow is dammed and, as a result, inundates the valley bottom of the flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement.
- In case of "F**loodwater diversion**", the wadi water is forced to leave its natural course and conveyed to nearby cropping areas.

These systems - the catchments being many square kilometers in size - require more complex structures of dams and distribution networks and a higher technical input than the other two water harvesting methods.

Fig 3: Example of Floodwater Harvesting / Floodwater Diversion and general features of Floodwater Harvesting
Source of figure: GTZ 1993;
Source of text: Prinz 1998

It is difficult to give exact figures on the present total area under the various forms of overland flow water harvesting. India’s leading position in this respect is undebatable. Pakistan will be second with more than 1.5 million hectares under Rainwater or Floodwater Harvesting. Fig. 4 shows the irrigated area under flood water harvesting in North Africa and the Middle East, according to FAO (1997), totalling about 2 million hectares.



* 1000 hectares

Figure 4: Area under flood water harvesting (‘spate irrigation’) in selected countries of North Africa and the Middle East
Source: FAO 1997

Traditional Use

Rainwater and Floodwater Harvesting have been practised in many dry regions of the world since millennia (Agarwal & Narain 1997, Prinz 1996):

Asia: In the Middle East archaeological evidence of water harvesting structures appears in Jordan, Israel, Palestine, Syria, Iraq, the Negev (Evenari et al. 1971) and the Arabian Peninsula (mainly the Yemen); the oldest being believed to have been constructed over 9,000 years ago.

In Baluchistan, Pakistan, two water harvesting techniques have a long tradition: the "Khuskaba" macrocatchment system and the "Sailaba" system, which utilises floods.

In India a great variety of rain water harvesting techniques developed over the last 2,000 years. In many areas, the "tank" system is traditionally the backbone of agricultural production; their total number is about 500.000. Ahars are important in Bihar region ; unlike tanks, the beds are not dug out. Out of the 46 million hectares under irrigation in India, about 6 million hectares are irrigated from "sources other than government canals, wells and tubewells", mainly various forms of water harvesting (Agarwal & Narain 1997, UNEP 1983, Sengupta 1993, Pacey and Cullis 1986).

Africa: In North Africa, water harvesting has a long tradition, too, and is still used extensively in Morocco, Tunisia and to a lesser extent in Algeria. Traditional techniques of water harvesting have been reported from many regions of Sub- Saharan Africa (Critchley et al. 1992), like the "Caag" and the "Gawan" systems in Somalia; various types of "Hafirs" in Sudan (UNEP 1983) and the ‘Zay’ system in Westafrica.

America: In America traditional water harvesting was practised by Indians e.g. in the Sonoran Desert and in the Chaco Canyon, New Mexico. In Arizona a lot of research was conducted recently on surface treatment to increase the runoff coefficient of catchments.

Benefits and limitations

Rainwater and Floodwater Harvesting have the potential to increase the productivity of arable and grazing land by increasing the yields and by reducing the risk of crop failure. They also facilitate re- or afforestation, fruit tree planting or agroforestry. With regard to tree establishment, water harvesting can contribute to the fight against desertification. Especially Rainwater Harvesting techniques are relatively cheap to implement and can therefore be a viable alternative where irrigation water from other sources is not readily available or too costly. Unlike pumping water, water harvesting saves energy and maintenance costs. Using harvested rainwater helps in decreasing the use of other valuable water sources like groundwater. **Remote sensing and Geographical Information Systems** can help in the determination of areas suitable for water harvesting (Prinz et al. 1998).

Although these methods can increase the water availability, the climatic risks still exists and in years with extremely low rainfall, it can not compensate for the shortage. Successful water harvesting projects are often based on farmers' experience and trial and error rather than on scientifically well established techniques, and can therefore not be reproduced easily. Agricultural extension services have often limited experience with it. Further disadvantages are the possible conflicts between upstream and downstream users, and a possible harm to fauna and flora adapted to running waters and wetlands.

Utilising Fog and Dew

Under specific environmental conditions fog and dew can be captured and can yield substantial amounts of water which can be used for domestic purposes, livestock, establishment of trees, or for the growth of crops. In order to supplement the moisture collected by plants themselves, artificial surfaces can be exposed such as netting-surfaced traps, or polyethylene sheets. Small and simple installations for the condensation of fog
or dew can yield several litres of water per day (Acosta Baladon 1995).

Collection of fog drip

Fog, the "suspension of very small, usually microscopic water droplets in the air", is provoked by the following conditions:

- Substantial heating during day time
- Clear skies or very light, high clouds at night
- No or very light wind
- A thermal inversion at moderate height
- A sufficiently high atmospheric humidity (Acosta Baladon 1995).

According to the conditions of fog formation we distinguish between (1) advection fog, (2) orographic fog, (3) catabatic fog and (4) frontal fog.

The possibilities to use fog for agricultural purposes are best in coastal , low precipitation areas with nearby cold ocean currents. Promising results are reported from Chile, Peru, Cape Verde Islands, Canary Islands and other coastal areas. Capture of the water droplets depends strongly on the movement of the air. In one location in Chile, up to 860 mm of fog could be captured in a year with barely 60 mm rainfall. To supply the village El Tofo in Chile with drinking water, a total captor capacity of 2400 m² was installed, which had a yield of 5 to 6 litres per m² of mesh per day, feeding a tank of 24.000 litres, supplying water at a cost of less than 1 $ per m³ (Acosta Baladon 1995).

Harvesting dew

Dew is defined as "the deposit of water droplets on objects the surface of which is sufficiently cool, generally by nocturnal radiation, to bring about the direct condensation of water vapour from the surrounding air". Dew formation is favoured by:

- A relative humidity at sunset of at least 75 %
- Wind speed less than 3 m/s
- Clear skies.

The effect of dew formation is strongest in valleys, as in mountainous areas the cooling air masses become heavier, flowing to the valley floors, where they continue to cool down, eventually leading to dew formation.

Dew measurements have rarely shown values above 40 to 50 mm per annum. Nevertheless in many dry, coastal areas of the world horticultural and agricultural crops are grown without irrigation, making full use of dew formation. The best known example is the cultivation of grapes and other horticultural crops on the island of Lanzarote, Canary Islands.

The collection of fog drip in coastal and higher mountain areas as well as the harvesting of dew in desert areas was practised already in ancient times.

Utilising Groundwater Without Lifting

Quanat systems

A Quanat is a horizontal tunnel that taps underground water in an alluvial fan without pumps or equipment, brings it to surface so that the water can be used. Quanat tunnels have an inclination of 1-2 ‰ and a length of up to 30 km (Fig. 5).

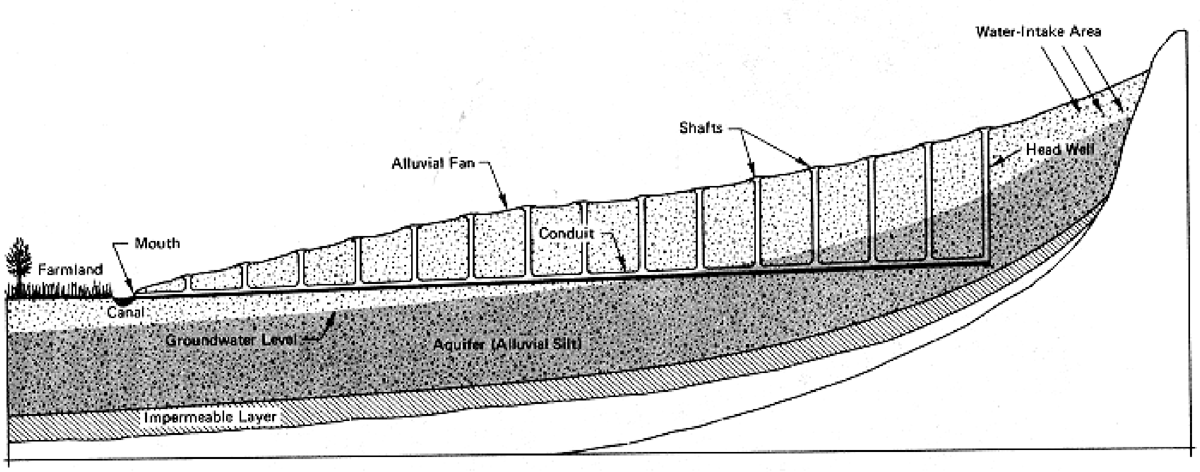


Figure 5 : Qanat-system conveying water by gravity to the ground surface
(Adapted from National Academy of Sciences 1974)

Traditional Use

The origin of the "quanat" technique is Persia, where it was developed about 3,000 years ago.

The knowledge spread to the neighbouring countries and later to whole North Africa and even to Spain. Many quanats were constructed in India, too, and are still in use in Kerala ("Surangam") and Madhya Pradesh ("Bhandara system") (Agarwal & Narain 1997).

Though new quanats are seldom built today, many old ones are still maintained and deliver steadily water to fields and villages. In Morocco, many of the large oases of the South receive a considerable amount of their irrigation water from quanats; the rest is harvested flood water.

Benefits and limitations

Since quanats can yield substantial quantities of water (5-60 l/s, in extreme cases up to 270 l/s; Achtnich 1980) and being a traditional method, the local people are aware of the values of this technique and more ready to maintain or restore it. On the other hand, quanats require relatively high labour input. Often they bear the maximum flow during the rainy season and the minimum flow during the dry season, as opposed to the demand for the irrigation water.

Kind of Storage

There are several options for long-term water storage:

- Aboveground
  - in small and medium-sized ponds and reservoirs
  - in large reservoirs behind dams.
- Underground
  - in small and medium-sized cisterns
  - in aquifers
  - in sand-filled reservoirs (with or without groundwater dams)

Above-ground Water Storage

The traditional irrigation methods mentioned above have the drawback of uneven water supply during the year. In the case of rain water harvesting, the agricultural production is even limited to the rainy season, if no storage (outside the soil matrix) is available. Therefore a number of storage media are employed, ranging from ferrocement tanks of a few m^2 content to large reservoirs, storing millions of m^3 of water (Fig. 6).

Figure 6 : Rainwater reservoir in Northern Vietnam (1.300 mm/a rainfall); water being used for paddy cultivation
Photo: Prinz

In India and Sri Lanka, hundred thousands of tanks store rain water, sometimes supplemented by water from streams or small rivers. Tanks play several important roles e.g.

- as **flood-control** system,
- in **preventing soil erosion**,

- in **preventing wastage** of runoff water during periods of heavy rainfall and
- they **recharge** the **groundwater**.

Further means of above-ground storage aside of tanks are 'ahars' (India), 'hafirs' (Sudan), natural and artificial lakes (e.g. 'nadis' and 'tobas' in India, 'lacs collinaires' in North Africa), and reservoirs with barrages.

There are several **disadvantages** connected with surface storage of water

- large evaporation losses,
- loss of storage volume caused by siltation,
- pollution problems and
- loss of agricultural land .

Underground Storage

Most problems associated with above-ground storage can be avoided by underground storage.

Cisterns

Cisterns are man-made caves or underground constructions to store water. Often the walls of these cistern are plastered; their water losses by deep percolation or by evaporation can be minimal. The construction of cisterns was already practised several thousand years ago; chalky rocks were preferred. Traditionally, in Mediterranean houses, one cellar room was specifically designed to store rainwater. Similar in-house cisterns are known from Rhajastan, NW India. Nowadays cisterns are often constructed using concrete (Fig. 7).

Figure 7: Concrete cistern of 3000 m^3 storage volume, constructed in Marsa Matruh area, NW Egypt . Photo: Prinz

Sand-filled Reservoirs and Groundwater Dams

Sand-filled reservoirs are used to store water in may arid regions; this technique has a number of advantages: (1) evaporation losses are reduced or even completely avoided, (2) the water stored is less susceptible to pollution, (3) health hazards such as mosquito breeding and spreading of snail fever are avoided, (4) no reduction in storage volume due to siltation. The main disadvantage is the general reduction in water storage volume per total volume (Nilsson 1988). In a few locations the natural geohydrological conditions allow the use of sand-filled reservoirs without any dam construction. But in most cases the advantages can only be gained when building a groundwater dam.

Groundwater dams obstruct the flow of groundwater or the subterranean flow of ephemeral streams and rivers in a river bed. The water is stored in the sediment below the ground surface. The stored water can be used to recharge an aquifer or to raise the level of an aquifer thus making it accessible for pumping.
There are basically two types of groundwater dams**: subsurface dams** and **sand storage dams** (Fig. 8). Groundwater dams were already constructed during Roman times in north Africa and on Sardinia. More recently general positive experience was gained with constructions in southern and east Africa, in Brazil and in India.

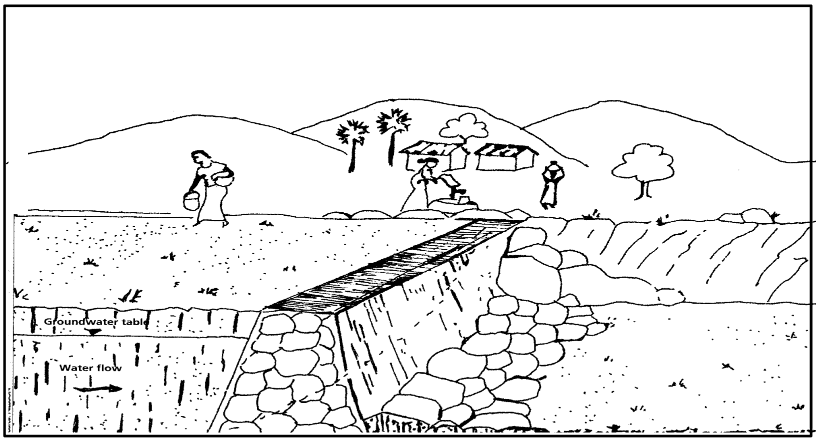


Figure 8: Sand storage dam
Source: Nilsson, 1988

Storing water in aquifers

In arid and semiarid regions, in future a significant amount of the water needed will have to be stored in aquifers. Storing water during times of flood and recovering it later during times of drought provides a cost-effective solution. Large water volumes are stored deep underground, reducing or eliminating the need to construct large and expensive surface reservoirs. In many cases, the storage zones are aquifers that have experienced long term declines in water levels due to heavy over-pumping. Recharge wells, percolation reservoirs or underground dams methods of artificial aquifer recharge in use.

Outlook

All the above mentioned techniques have the advantage to increase the amount of water available for agricultural and other purposes, and to ease water scarcity in arid and semi-arid areas. They require relatively low input and, if planned and managed properly, can contribute to the sustainable use of the precious resource water.
The results of traditional irrigation methods are encouraging and should be promoted,
but the methods described above have to be supplemented by **application techniques** of high efficiency. All the engineering skills of scientists and practitioners are asked for to offer cheap and efficient supply systems.
There are numerous examples of interesting new applications which combine overland flow water harvesting with **supplemental surface** or **subsurface irrigation.** In subsurface irrigation the water distribution can be performed by using perforated plastic pipes (e.g. research at the ‘Institut des Regions Arides’ in Medenine, Southern Tunisia) or with clay pipes of specific make, as applied by Bastani (1998):

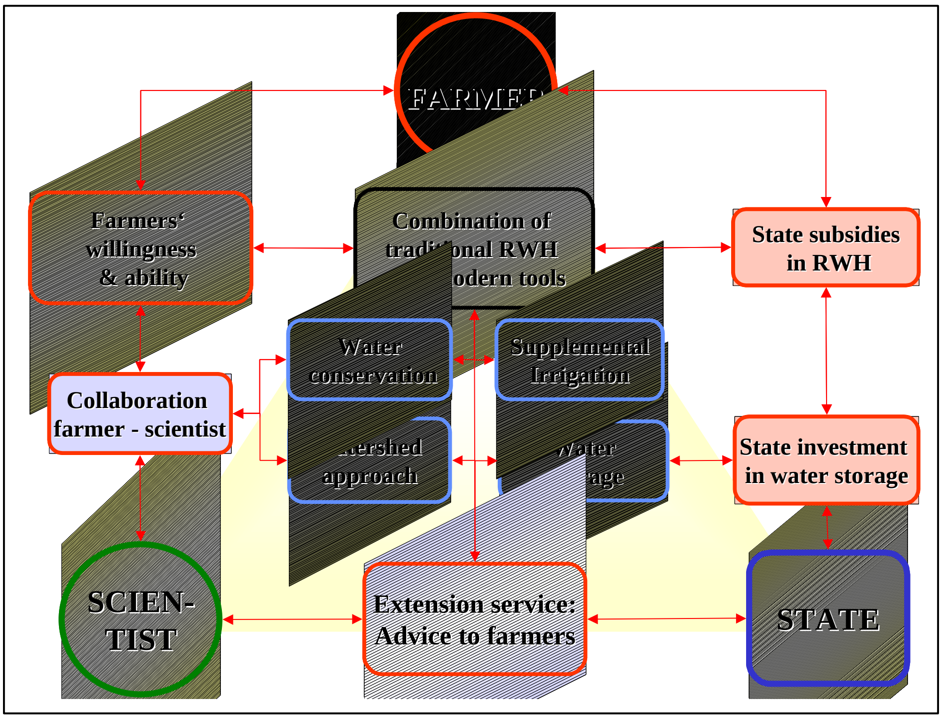


Fig. 9: The cooperation between farmers, the State and the scientific community is needed to arrive at a wider use and a higher efficiency of Water Harvesting.

During recent years some methodological and technological developments took place in regard to the combination of water harvesting techniques combined with **modern tools**, like application of remote sensing data, hydrological models, water conservation and efficient irrigation techniques. A **watershed approach** should be practised, not only to avoid problems between upstream and downstream users, but also to leave sufficient quantities of water for natural flora and fauna.

As most farmers practising water harvesting are resource-poor peasants or herders, some intervention of **state** authorities is needed, e.g. financing the construction of small reservoirs or subsidizing greenhouses or underground / drip irrigation installations.

In some cases the available knowledge is sufficient to solve a specific problem, but the application or the promotion by state / local authorities is lacking. A state supported **extension service** is a must, if new tools shall be successfully applied.

In other cases, further research and experimentation is still required before a certain method can be recommended. **Scientific research** should then be carried out in collaboration with farmers; the results of applied research should be passed on to the farmers via the extension service.

Water management problems can only be tackled in an **holistic way**. Production increases by improved irrigation have to be paralleled by promoting adequate employment and balanced regional development.

The potential is there, and hopefully, sustainable traditional water supply / irrigation methods will also receive the required backing of politicians and planners, who become aware of the potential of these ‘old’ and most probably also ‘modern’ techniques to reduce water related problems in the twenty-first century.

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