OPPORTUNITIES TO EASE WATER SCARCITY (WATER CONSERVATION TECHNIQUES AND APPROACHES; ADDED VALUES AND LIMITS)

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ABSTRACT

In areas where rainfed agriculture is not feasible, the water used for farming and domestic purposes stems usually from running waters and dams or wells. Any method that saves water, most especially the application of sources other than river water, reservoir water or pumped groundwater, can be termed a water conservation method. Traditional water conservation techniques have been practised in many dry areas since millennia. Some examples mentioned in the text are water harvesting, quanats, artesian wells and horizontal wells. The revival and improvement of these methods would provide excellent opportunities to ease the water scarcity in the arid and semi-arid areas of the world.

KEYWORDS

Water conservation, traditional irrigation techniques, water harvesting, quanats

INTRODUCTION

When it comes to supplying water for irrigation and domestic purposes, most people think of rivers and large reservoirs or of bore holes, which tap ground water resources. Indeed, a large proportion of the water for irrigation is taken either from streams and rivers or from reservoirs and aquifers, but this is not the full picture. In India, for example, about 40 million hectares are irrigated using these sources, whereas some 6 million hectares are irrigated from „other sources". In Indian statistics, these „other sources" are summarised as „sources other than government canals, wells and tubewells" (Sengupta 1993). Yet, what does the term, „other sources," stand for? Behind this term are various water conservation techniques and traditional irrigation methods, mainly various forms of water harvesting. These traditional techniques played a much greater role in the past and were the backbone of ancient civilisations in arid and semi-arid areas around the world (Prinz 1996). Besides water harvesting, other traditional techniques, which tap into groundwater resources, like the quanat-systems, are still used widely. These two techniques make it possible for plants to utilise the water immediately or for it to be stored in reservoirs for later use in the dry periods of the year. A third group of traditional techniques which ease water scarcity are related to in-situ-water conservation.

Water scarcity will be one of the major threats to humankind in the next century. As the available water resources taken from streams, rivers and ground water will not be sufficient in dry areas to cover the needs of agricultural and urban areas, we have to reassess the value of traditional water conservation techniques and find out their potential to ease water scarcity. During the last two decades, traditional techniques have gained importance, and renewed interest in them can be observed among researchers as well as practitioners.

HISTORICAL BACKGROUND

Since ancient times, farmers and herders in dry areas of the tropics and subtropics have, under a wide range ecological conditions, attempted to conserve water and to increase agricultural production. A number of indigenous water conservation techniques can be found in areas which have between 100 and 1500 mm annual precipitation and with population densities varying from 10-500 persons / $km^{2.}$

Some traditional techniques, which

1. Make better use of rainfall
2. Make use of fog and dew
3. Make use of groundwater without water lifting

shall be described in the following in more detail:

Making better use of rainfall

Minimisation of runoff losses (in combination with increased infiltration) and the collection and concentration of rainfall (including storage) are the most important approaches in making better use of the scanty rainfall in arid and semiarid areas.
In tropical and subtropical countries, many indigenous agricultural practices are directed towards minimizing runoff losses in combination with protecting the soil resources, i.e. they contain certain elements of water and soil conservation. In other cases, the moisture conservation effect is a secondary effect of soil conservation, as shown in traditional techniques such as constructing dry stone bunds or terraces.

There are, then, also a number of traditional techniques which are primarily directed to in-situ moisture conservation. For example we have the application of the "zay" technique, which is common in Mali and Burkina Faso. The "zay" system consists of small pits, 5 - 15 cm in depth and 10 - 30 cm in diameter. The pits are spaced out, leaving 50 - 100 cm between them (Wright 1985). Manure and grasses are mixed with some of the soil and put into the zay to increase nutrient status and water holding capacity (Fig. 1). The pits fill up when it rains, and the water infiltrates into the soil where it is stored. With modification of the area between the pits, such that it serves as a "catchment", the "zay" could be regarded as a water harvesting technique (see below). Zays are often applied in combination with bunds to conserve runoff.

Fig. 1: "Zay" pitting holes in Burkina Faso, serving improved soil moisture and soil fertility, after rainfall Photo Dudeck)

Rainfall collection and concentration, also called "Water Harvesting", has been practised in many dry regions of the world since millennia:
Asia: The outstanding importance of the Middle East in the development of ancient water harvesting techniques is unquestioned. Archeological evidence of water harvesting structures appears in Jordan, Syria, Iraq, the Negev and the Arabian Peninsula, especially Yemen.
In Jordan, there is indication of early water harvesting structures believed to have been constructed over 9,000 years ago.
The internationally best known runoff-irrigation systems have been found in the semi-arid to arid Negev desert region of Israel (Evenari et al. 1971). Runoff agriculture in this region can be traced back as far as the 10th century BC when it was introduced by the Israelites. It continued throughout Roman rule and reached its peak during the Byzantine era.
In Northern Yemen, a system dating back to at least 1,000 BC diverted enough floodwater to irrigate 20,000 hectares (50,000 acres) producing agricultural products that may have fed as many as 300,000 people (Eger 1988). Farmers in the same area are still irrigating with floodwater, making the region perhaps one of the few places on earth where runoff agriculture has been continuously used since the earliest time of settlement.

In the South Tihama of Saudi Arabia, flood irrigation is traditionally used for sorghum production. Today, approximately 35,000 ha land, supporting 8,500 to 10,000 farm holdings, are still being irrigated with flood waters (Wildenhahn 1985).
In Baluchistan, Pakistan, two water harvesting techniques were already applied in ancient times: the "Khuskaba" system and the "Sailaba" system. The first employs bunds being built across the slope of the land to increase infiltration. The latter utilizes floods in natural water courses which are captured by earthen bunds (Oosterbaan 1983).
In India's arid and semi-arid areas, the "tank" system is traditionally the backbone of agricultural production. Tanks are constructed either by bunding or by excavating the ground and collecting rainwater. In West Rajastan, with desert-like conditions having only 167 mm annual precipitation, large bunds were constructed as early as the 15th century to accumulate runoff. These "Khadin" create a reservoir which can be emptied at the end of the monsoon season to cultivate wheat and chickpeas. (Kolarkar et al. 1983). A similar system called "Ahar" was developed in the state of Bihar (UNEP 1983, Pacey and Cullis 1986). Ahars are often built in a series. It was observed that brackish groundwater in the neighborhood of Ahars became potable after the Ahar was built.
In China's loess areas a very old flood diversion technique called "warping" is found, which harvests water as well as sediment.
Africa*:* Since at least Roman times, water harvesting techniques were applied extensively in Northern Africa. Archeological research revealed that the wealth of the "granary of the Roman empire" was largely based on runoff irrigation (Gilbertson 1986).
In Morocco's Anti Atlas region, Kutsch (1982) investigated the traditional water harvesting techniques, some of which are still practised today. He found a wealth of experience and a great variety of locally well adapted systems. In Algeria, the "lacs collinaires", the rainwater storage ponds, are a traditional means of water harvesting for agriculture. The open ponds are mainly used for watering animals.
In Tunisia, the "Meskat", the "Jessour" and the "Mgoud" systems have a long tradition, and are also still practised. The "Meskat" is a microcatchment system which provides fruit tree plantations with about 2,000 m3 extra water during the rainy season (Fig. 2); the "Jessour" system is a terraced wadi system with earth dikes ("tabia"). Lastly, the "Mgouds" are channel systems used to divert flood water from the wadi to the fields (Tobbi 1993).

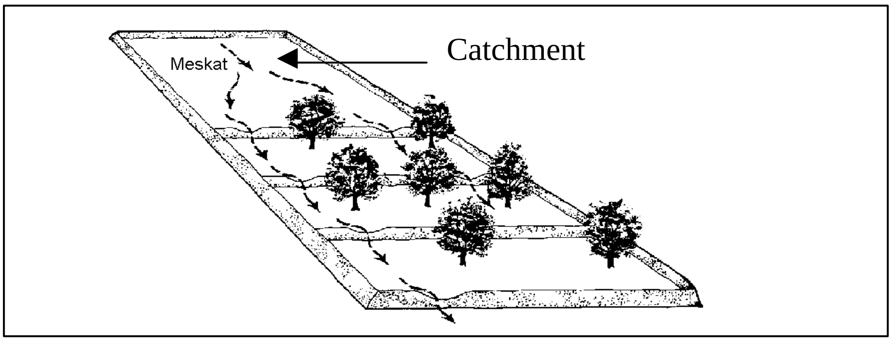

Fig. 2: The Tunisian "Meskat" water harvesting system (Adapted from El Amami 1983)

In Egypt, the North-West coast and the Northern Sinai areas have a long tradition in water harvesting. Some wadi terracing structures have been there used for over centuries.
Traditional techniques of water harvesting have been reported from many regions of Sub Saharan Africa (Critchley et al. 1992a): The "Caag" and the "Gawan" systems are practised in Somalia. The former is a technique used to impound runoff from small water courses, gullies or even roadside drains; the latter is made up of small bunds which divide plots into "grids" of basins of 500 m^2 or above in size. In Sudan, various types of "Hafirs" have been in use since ancient times. Their water is used for domestic and animal consumption as well as for pasture improvement and paddy cultivation (UNEP 1983).
The Haussa in Niger and the Mossi in Burkina Faso traditionally divert water to their fields with rock bunds, stalks and earth or construct rock bunds and stone terraces.
America: Traditional water harvesting was practised in the Sonoran desert by the Papago Indians and other groups. Brush weirs were used to spread the floodwaters .

Elsewhere, fields were irrigated by gravity-fed channels (arroyos) leading water from earth and stick or rock diversion weirs. A highly sophisticated distribution system was demonstrated by the flood water diversion system of Chaco Canyon, New Mexico.

Making use of fog and dew

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. Many localities of the world, including arid zones, are often covered by low clouds, for example in Mexico, Chile, Colombia, Sudan, Yemen, Oman etc.. With regard to dew collection is still disputed, whether various structures excavated in ancient settlements (e.g. in the Negev) were really serving this purpose and what water yield they could have achieved. On the Crimean, a system of earthware pipes and stone cones of up to 10 m height were discovered, which are believed to have served as condensation promoters (Acosta Baladon 1995).

Making use of groundwater without water lifting

Quanat systems (Fig. 3) and the use of water from Artesian wells have a very long history: The origin of the "quanat“ technique is Persia, where it was developed about 3,000 years ago. The Persians of that time learned to dig tunnels to bring mountain groundwater to arid plains. This knowledge spread to the neighboring countries and was distributed by the Muslim Arab invaders throughout North Africa all the way up to Spain. Though new quanats are seldom built today, many old ones are still maintained and deliver water steadily to fields and villages. In Iran there are still some 40,000 quanats comprising more than 270,000 km of underground channels that supplied about 35 percent of the country’s water two decades ago (National Academy of Sciences 1974). Rehabilitation programs were started in a number of countries such as Oman and Morocco.

Fig. 3 : Craters, each marking the mouth of a quanat shaft in Southern Morocco. Groundwater from the Higher Atlas mountains is directed to an oasis in the plains (Photo Prinz)

When digging bore-holes in (semi-)arid areas, ancient farmers detected the special nature of Artesian wells, which deliver ground water without any need to lift it. Some of them have been in use for more than 2,000 years.

GENERAL OVERVIEW

To ease water scarcity in dry areas without using irrigation water from permanent rivers, reservoirs or lifted groundwater, several methods can be applied (including the ancient techniques mentioned above):

1. Making better use of rainfall by
   - minimizing runoff losses (in combination with increased infiltration)
   - collection and concentration of rainfall (including storage)
   - minimizing evaporation losses

- minimizing transpiration losses
- improving rainwater usage by plants

2. Making use of fog and dew by
   - collection of fog drip
   - harvesting dew

3. Making use of groundwater without water lifting by
   - quanat systems
   - artesian wells
   - horizontal wells.

MAKING BETTER USE OF RAINFALL

Minimizing runoff losses (in combination with increased infiltration)

Examples of such techniques are:

- ridges, constructed along the contour
- stone lines made of single or multiple rows of stones
- trash lines, made of organic residues such as straw, maize stokes, weeds, etc.
- furrows, with crops being grown at the bottom of the furrows or at the edges;
- tied ridges
- pitting systems: either manually prepared (the crops are grown in small depressions of 30 cm diameter with soil improved by organic material) or by tractor-pulled implements
- terraces: induced terraces, constructed terraces, conservation terraces
- mulching: covering the soil with organic material
- contour farming
- strip cropping
- conservation tillage or no tillage
- agro-forestry techniques, e.g. planting of Faidherbia albida.

Projects in a number of countries have shown that moisture conservation techniques are accepted by farmers as they can decrease the production risk considerably and increase the average yield significantly (Critchley et al. 1992b).
Experiments in Kanguessanou, Kayes Province, Mali (550 mm/a precipitation), have shown, that bunding, i.e. the construction of an earth dike around the field, could increase the yield of Sorghum from 0.8 t /ha to 1.8 t / ha, even in dry years (Klemm 1990).

Collection and concentration of rainfall (including storage)

The collection and concentration of rainfall and its use for the irrigation of crops, pastures, trees, livestock consumption and household purposes is often called water harvesting. In the past, water harvesting played an important role for agricultural societies in arid and semi-arid areas world-wide. After a decline, it picked up new interest in recent decades.

Each water harvesting system requires a:

- "runoff area" (catchment) with a sufficiently high run-off coefficient and
- "run-on" area for utilization and / or storage of the accumulated water, in case of agricultural use the cropping area

According to the size of the catchment and the relation between the size of the catchment and that of the cropping area, one can distinguish three major types of water harvesting: microcatchment water harvesting,

macrocatchment water harvesting and large catchment water harvesting. The higher the aridity of an area, the more catchment area is required in relation to the cropping area in order to yield the same amount of water.
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.
Water harvesting from macrocatchments is also called "water harvesting from long slopes" or "harvesting from external catchment systems" (Pacey & Cullis 1988). In this case, the catchment located outside the cropping areacollects mainly turbulent runoff and channel flow. This is conveyed to the cropping area located below the foot of the hill on flat terrain.
As the name suggests, the catchments of large catchment water harvesting systems can be many square kilometers in size and give rise to runoff water flowing through major wadis. Large catchment water harvesting is also called floodwater harvesting by many authors, and 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 entire flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement. In case of "floodwater diversion", the wadi water is forced to leave its natural course and conveyed to nearby cropping areas. Large catchment water harvesting requires more complex structures of dams and distribution networks and a higher technical input than the other two water harvesting methods.

Fig. 4: Microcatchment water harvesting for growing trees (Photo Missaoui)

Minimizing evaporation losses

Only part of the rainfall or irrigation water can be used by the plants, the rest percolates into the deep groundwater, or is lost by evaporation from surfaces and evapotranspiration by plants. There are numerous methods to reduce such losses and to improve soil moisture, of which the most important ones are:
Mulching, i.e. the application of organic or inorganic material, such as peat, plant debris, straw, etc., which slows down the surface runoff, improves the soil moisture and reduces evaporation losses.
Soil cover by crops slows down runoff, and minimises evaporation losses. An additional advantage is the possibility of nitrogen fixation by specific plant species or the use of the cover for grazing.
Ploughing can hinder the capillary movement of water in the soil and, as a consequence, reduce the evaporation.
Shelter belts consisting in most cases of bushes or trees slow down the wind speed near the crops, thereby reducing evaporation, erosion and physical damage to crops. At the same time, they may increase precipitation and serve as fodder, fuelwood etc.
Some chemicals such as emulsions of water and oil or wax (hexadenol, bitumen, asphalt, latex), reduce evaporation when sprayed on soil or water surfaces (Barrow 1987).

Minimizing transpiration losses

The aforementioned shelter belts which reduce evaporation losses due to a reduction of wind speed, also reduce water loss through transpiration in plants.
If crops are sprayed with Kaolinite and water, they are heated up less by the sun and therefore loose less water by transpiration. Also wax emulsions, silicone or latex applied directly on the plant, may reduce transpiration.
An optimal solution would be to select crops which have a low evapotranspiration by nature, as many of those endemic to dry areas.

Improving rainwater usage by plants

The improvement of rainwater usage by plants means the improvement of soil moisture retention, together with decreased percolation, and an increase in the availability of stored water for plants.
The addition of organic matter such as compost, peat, seaweed, paper and crushed coal to the soil leads to higher moisture retention. A positive side effect of the application of organic matter is improved soil fertility. Some artificially produced compounds such as starch copolymers or granular polymers (PAM = Polyacrylamid) have been applied successfully as well (Barrow 1987).
Special care should be given to the selection of crop species. One should seek varieties suitable to the site, for example those that develop a fine and deep rooting-system.

MAKING USE OF FOG AND DEW

Fog and dew contain substantial amounts of water that can be used directly by adapted plant species. In order to supplement the moisture collected by plants themselves, artificial surfaces can be exposed such as netting-surfaced traps, or polyethylene sheets. The resulting water can be used for domestic purposes, livestock, establishment of trees, or for the growth of crops. Small and simple installations for the condensation of fog or dew can yield several litres of water per day (Acosta Baladon 1995).

MAKING USE OF GROUNDWATER WITHOUT WATER LIFTING

Quanat systems

A Quanat (Fig. 5) is a horizontal tunnel that taps underground water in an alluvial fan without pumps or equipment, and brings it to surface so that the water can be used (National Academy of Sciences 1974). A quanat system is composed of three parts:

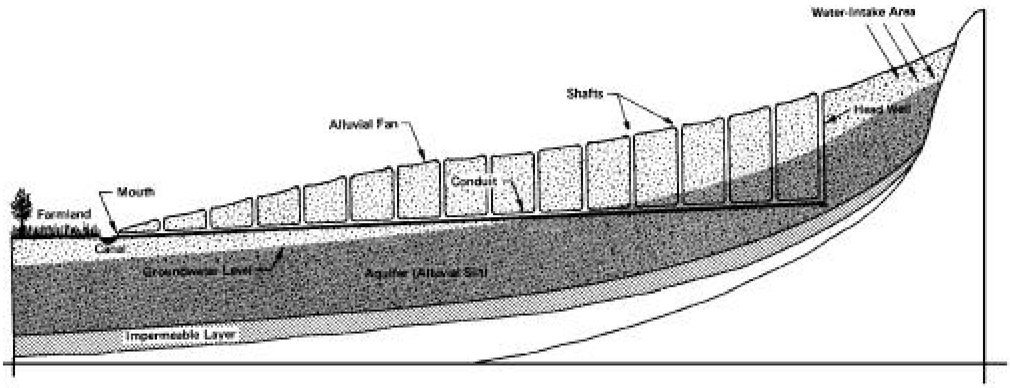

Fig. 5: Quanat-system conveying water by gravity to the ground surface (Adapted from National Academy of Sciences 1974)

- one or more vertical head wells, dug into the water-bearing layers of the alluvial fan, to collect the water
- a gently downward-sloping underground horizontal tunnel leading the water from the head wells to lower point at the surface
- a series of vertical shafts between the ground surface and the tunnel, for ventilation and removal of excavated debris.

Quanats, bringing ground water from mountainous areas to arid plains, have an inclination of 1-2 ‰ and a length of up to 30 km, yielding water in the range of 5-60 l / s, in extreme cases up to 270 l /s (Achtnich 1980, National Academy of Sciences 1974).

Artesian wells

Artesian wells tap groundwater of aquifers where the water is confined by an overlying, relatively impermeable layer and the pressure is sufficient to raise the water in a well without pumping. This type of spring can have a high water yield.

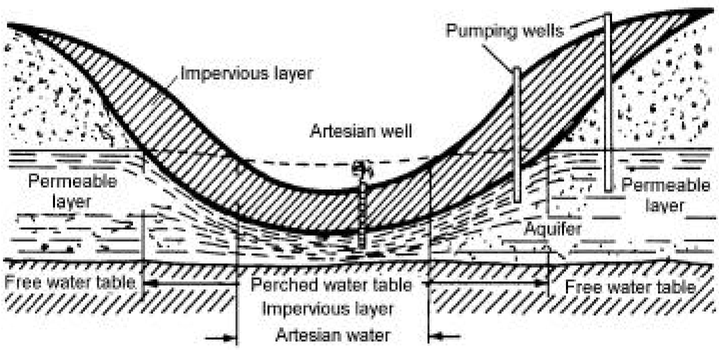

Fig. 6: Artesian groundwater (Adapted from Achtnich 1980)

Horizontal Wells

Horizontal wells tap underground water which is trapped by an impervious geological barrier. They are installed by boring a hole with a horizontal boring rig and inserting a steel pipecasing.

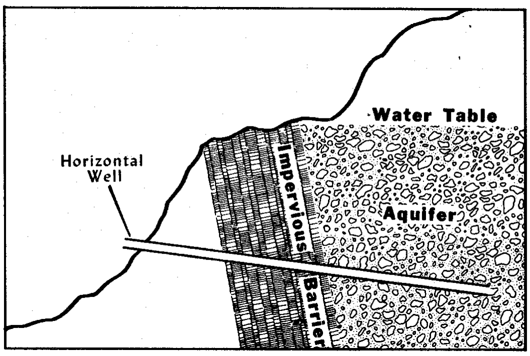

Fig. 7: Horizontal Well (National Academy of Sciences 1974)

ADDED VALUES

All the above mentioned techniques have the advantage of increasing the amount of water available for agricultural and other purposes, and easing 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 water.
Water Harvesting has the potential to increase the productivity of arable and grazing land by increasing the yields and by reducing the risk of crop failure. It also facilitates re- or afforestation, fruit tree planting or agroforestry. With regard to tree establishment, water harvesting can contribute to the fight against desertification. Water harvesting is relatively cheap and can therefore be a viable alternative where irrigation water from other sources is not readily available or too costly. Unlike pumping water for animal consumption, water harvesting saves energy and maintenance costs. Using harvested rainwater helps to decrease the use of other valuable water sources, such as groundwater.
Properly applied methods of evaporation loss reduction, such as the application of mulch and the careful ploughing or planting of shelter belts have proved to be beneficial for plant establishment, plant growth and yield, but also for erosion control and prevention of further land degradation.
Since quanats are a traditional method, the local people are aware of this technique and more ready to implement or revive it.
Artesian wells provide a low-cost possibility for steady access to sufficient water resources. Horizontal wells are relatively low-cost; no pumps are needed and the yield can be controlled. There is no danger of contamination by dust or animals.

LIMITATIONS

It is well acknowledged that the above mentioned techniques have more advantages than disadvantages Nevertheless, some drawbacks may occur. Although water harvesting can increase the water available for plants, climatic risks still exist. Further, in years with extremely low rainfall, it can not compensate for the shortage. Water harvesting provides no guarantee for high yields, since yields do not depend on water only, but also on other factors such as soil fertility, pest control, etc. The labor input required for water harvesting is often higher than that of rainfed farming. Successful water harvesting projects are often based on field 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 users upstream and downstream, and a possible harm to fauna and flora adapted to running waters and other wetlands.
The application of chemicals for the purpose of lowering evaporation and transpiration is relatively expensive and might not be suitable for developing countries (Barrow 1987). In addition, the environmental impacts have not been fully researched.
Quanats require relatively high labour input and maintenance. They bear a maximum flow during the rainy season and a minimum flow during the dry season, as opposed to the demand for the irrigation water. Under certain circumstances, they may dry up completely for a certain time. The areas that can be supplied with water from quanats lie at lower elevations of alluvial fans and provide less fertile soil conditions than those areas which are higher up. As for all situations, where groundwater is extracted, there is a risk of exploiting more water than can be recharged by natural processes in the same year.
Artesian wells depend on the presence of perched water tables and might not be available. They have the drawback that they provide water all the time, the volume per second depending on the natural pressure . Unused water might therefore be wasted. Horizontal wells are a good and simple method, but they can only be used where the geological conditions exist. The technical installation requires some experience.

OUTLOOK

Although the results of traditional water conservation methods are encouraging and should be promoted, the ancient and current methods to ease water scarcity might not be efficient enough to compensate for extreme climatic conditions, global climate change and the increasing demand for agricultural production due to an

excessive population growth. In some countries, the water is so scarce, that every available measure is used to preserve literally every drop of rain. Costs increase with the effectivity of the application of water conservation methods. In water harvesting, for example, it might be easy and cheap in a specific setting, to collect 50% of the runoff, but with increasing harvest, the costs per unit collected water increase considerably. Nevertheless, in countries like Marocco, high investment is made in order to meet the water demand.
During recent years some methodological and technological developments took place with regards to rainfed farming in combination with a water conservation technique, or the combination of two or more different water conservation techniques. Water harvesting, for example, can be used as supplemental water source for rainfed agriculture, when the runoff is stored for application after the rainy season. The stored water allows for a lengthening of the cropping season or for a second crop. Water harvesting has been used in combination with underground dams that recharge the groundwater. In Morocco, for example, water harvesting and quanats are used for water supply for the same area, thereby reducing the risks involved and saving some groundwater.
Much research and much practical experience is still required before scientists will be able to recommend a particular method off-hand. As soon as more information on the hydrological, soil and crop parameters is available, models could be applied for comprehensive water management plans in certain areas. The potential is there, and hopefully, sustainable traditional water conservation methods will also receive the required backing of politicians and planners, who are aware of the scarcity of the resource water and the need to preserve this resource, which is so essential for life on earth.

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