# Rainwater harvesting in dry areas

## The case of rural Gansu in China

**Qiang Zhu**

**The loess plateau of Gansu China is one of the driest and poorest areas of the country. The serious water scarcity caused many problems in the pastno safe - access to domestic water supply, frequent droughts and low agriculture levels, the impoverishment of the local population, land degradation and environment deterioration. Since the late 1980s, however, rainwater harvesting has been studied, demonstrated and replicated on a large scale. It has supplied water for millions of rural people to meet their basic needs, with water also to enhance crop production. It has played an important role in conserving the environment. Its importance in the sustainable development of the dry mountainous area needs to be properly appreciated. This article also gives a brief description of the RWH system.**

**Prof. Qiang Zhu**
*Research Professor (retired) of Gansu Research Institute for Water Conservancy, China*
*Residence address:*
*Room 702, No. 24 Hongshan Huayuan, Binhu District, Wuxi City 214072, China*
*Tel/Fax: (+86) 510 8588 0170*
*E-mail: qiangzhz@hotmail.com*

## Background

The loess plateau located in the middle and eastern part of Gansu, a northwest province of China, is one of the driest and poorest areas of the country. It has an area of about 150,000 sq. km, with altitudes ranging from 1500 to 2500 m above sea level. The annual precipitation is 330 mm, while the potential evaporation is around 2000 mm. Several tributaries of the Yellow River flow through it but lie hundreds of metres below the land. Owing to the weather and geological conditions, only 10 per cent of the rainfall can run off into the river. Moreover, due to the high mineral content in the soil, the basic river flow formed by the infiltrating rainfall is bitter and salty and cannot be used for domestic purposes or even for irrigation. Groundwater is very rare and of bad quality. Renewable water resources (river flow plus rechargeable groundwater) per capita are only 260 $m^3$, the lowest level that can sustain human existence. This serious water scarcity has highly adverse effects on the lives and productivity of the people.

Before 1995, as many as three million local people had no access to safe drinking water. It usually took several hours for the women and children to fetch even the highly saline water located in the deep valley. In many villages, people had to use the only pond together with their animals. In the dry period, even this low quality water would dry up. The government had to dispatch hundreds of trucks to transport water from a great distance.

The agriculture in the area is totally dependent on natural rainfall, which, however, has always had an unfavourable distribution in and between years. Droughts were frequent. In the 41 years from 1950 to 1990, there were 36 droughts. The yield of the main staple crops was only round 1.8 mt per ha and the grain owned by each person was 284 kg, or about 70 per cent of that in the rest of the province. In some dry years, the harvest could not even compensate for the seeds.

Another result of the water shortage has been the structure of farming. Without water, farmers could not grow any cash crop and, as a result, had a very low income. The yearly net income per capita was only $ 60-100. Millions of people lived around the poverty line. Many people in the mountainous area never saw the "fine vegetables" (pepper, tomato, cucumber, eggplant, etc.) on their dining tables before the 1990s.

Owing to the low land productivity, the farmers reclaimed as many lands as possible to get enough food for an ever increasing population. Even land on slopes steeper than 25° was planted with grain crops, despite the low yield. This practice sped up environmental deterioration and land degradation. The erosion is as high as 5,000-10,000 t/km$^2$ per year, which means that each year there will be about 0.5-1 cm of surface soil being stripped off. As a result of the land degradation, the agriculture condition further worsened. It was a vicious circle: the poorer they were, the more they reclaimed. The more they reclaimed the poorer they would be.

The key measure to change these basic conditions for social and economic development and to raise living standards is to solve the water problem. This can be done in two ways.

One is to build an inter-basin water diversion project that will introduce water from outside the area. At the end of the 1950s, an ambitious scheme to divert water from the Taohe River, one of the largest tributaries of the Yellow River, had been started without due consideration of the economic and technical capacities. The work could therefore continue for only two years, leaving in its wake a useless canal section and a huge waste of funds.

The project was redesigned in the 1990s on a much smaller scale and construction resumed only recently. It will still take time to bring in profits. Moreover, the topography of the area is very unfavourable. Numerous gullies crisscross the area, making it very difficult to build the water conveyance system. The scattered population in the mountainous area cannot fully benefit from this centralized project. The high costs of O&M, hardly affordable by the users, will also be a problem for the sustainability of the water diversion project.

## RWH - the innovation

Another way is to use the potential of the available water resource in the area, the rainwater. Although rain is relatively rare, the total amount of rainfall falling on the entire area of 150,000 sq km is as high as 54 billion cu m, much more than the yearly runoff of the Yellow River at the Lanzhou section. Of this total rainfall, it is estimated that around 10 per cent forms river runoff, 15-25 per cent is directly absorbed by the crops and the remaining 65-75 per cent is consumed by ineffective evaporation. Clearly there is a high potential for rainwater utilization.

On the other hand, there are certain unfavourable conditions for rainwater utilization too. The low yearly rainfall and the unfavourable distribution during a year and between years limit the efficient use of the rainwater. Only by concentrating the rainfall can the full use of rainwater be feasible. This concentration is done in two ways. Concentration in a temporal sense involves storing the rainwater collected in the rainy season for use in the dry spell. Concentration in a spatial sense implies enlarging the rainwater collection area and meanwhile enhancing the rainwater collection efficiency .

The local people have a tradition of utilizing rainwater for their daily use. All families have a water cellar (a kind of underground tank, locally known as *Shuijiao*) to store rainfall in the rainy season for their daily use. But their rainwater collection field is mainly natural soil, so collection efficiency is very low. In light rain, little runoff can be produced. In a rainstorm, the water collected is mixed with soil and dirt and hence of very bad quality. Thus this traditional system has not been able to ensure enough supply of water for domestic use. Needless to say, it is not able to provide water for crop production.

Seepage from the *Shuijiao* in ancient times was prevented by pasting straw-clay mud on the wall and at the bottom of the tank. This method involved a large labour force, in spite of which it was difficult to ensure quality. The frequent resulting leakages not only caused the loss of the valuable water, but also caused the collapse of the loess soil, thus damaging the cellar. Until 1988, each rural household owned 2.2 water cellars on average, yet most of them still suffered from thirst.

With the support of the Provincial Government, the Gansu Research Institute for Water Conservancy (GRIWAC) carried out a research and demonstration project on Rainwater Harvesting (RWH) in a 4-year period, from 1988 to 1992. The main purpose was to find a way to enhance rainwater utilization efficiency which comprised rainwater collection efficiency (RCE), storage efficiency and use efficiency. Different patterns of RWH systems for domestic and production use were tested and proved to be very successful. Thousands of demonstration projects were set up to show the people and the authorities the significance of using rain in this area. The research findings were replicated in the following three years in the domestic RWH systems of 40,000 households. An RWH system was also built to supply supplementary irrigation for crop lands to raise yield. With water in the tank, GRIWAC has helped farmers to build simple greenhouses, growing vegetables for their income generation. For the first time local famers enjoyed the "fine" vegetables, harvested on their own land.

In 1995, a serious drought, that had not been seen for 60 years, occurred in the area. Millions of people had no water source for their domestic use. Almost all the summer the wheat died out. Viewing the successful result of the GRIWAC's demonstration and extension project, The Gansu Provincial Government decided to initiate the "1-2-

**Table 1: Yearly mean RCE of different kinds of catchment (%)**

| Type of catchment | Concrete lined surface | Cement tiled roof | Clay tile (factory made) | Clay tile (workshop made) | Cement soil | Buried plastic film | Compacted soil | Natural earthen slope |
|---|---|---|---|---|---|---|---|---|
| RCE | 73-80 | 62-75 | 30-50 | 24-41 | 33-53 | 28-46 | 13-25 | 0.08-0.1 |

1” Rainwater Catchment Project in areas where surface and groundwater are not available and rain is the only source. The government would support each family with US$ 50 to build one catchment area and two storage tanks and to set up one piece of land for a cash crop. Tiled roofs and courtyards lined with concrete slabs - with a total area of 100-150 m$^2$, depending on the annual rainfall - are used for the catchment, and two *Shuijiao*'s installed in the courtyard are for storage. From July 1995 through the end of 1996 the project achieved great success. The artificially treated collection fields, including the tiled roof and lined courtyards with concrete, were of the order of 37.16 million m$^2$; and as many as 286,000 newly designed water cellars were built. As many as 1.3 million rural people in 2,018 villages under the jurisdiction of 27 counties solved their drinking problems. Besides, some 1,330 ha of land received supplemental irrigation from the RWH system.

With the successful “1-2-1” Project, the local government and people recognized the potential of rain. In 1996, the government launched a Rainwater Harvesting and Irrigation Project. The target was to develop 33,333 ha of land with the RWH irrigation system each year over a 10-year period. There were several differences from the RWH system for domestic supply.

- Various less permeable surfaces of existing structures were used for catchment, including the paved highway, country roads, threshing floors and sports grounds.
- The storage tanks were built near the field, usually at a place higher than the crop field so the irrigation water could flow by gravity. Sometimes even the level difference could provide enough head for the pressurized irrigation systems, like drip, micro-spray and bubble irrigation.
- The storage capacity was usually 30-60m$^3$, which can supply water for 1-2 *Mu* (a Chinese land unit equivalent to 667 m$^2$ or 1/15 ha) with highly efficient irrigation methods. According to official statistics, till the end of 2007, as many as 72,195 ha of crop fields, 10,829 ha of greenhouses and 270,730 ha of orchards got irrigation supply from the RWH system.

## The RWH system in Gansu

The RWH system has three components: a rainwater collection subsystem, a storage subsystem and a water supply and irrigation subsystem.

### Collection subsystem

The rainwater collection sub-system consists of a collection field (the catchment), an interception canal, a collection canal and a conveyance canal. The collection field can be divided into three categories: the natural slope (earthen or rocky), the less permeable surface of an existing structure and a purpose-built catchment. In the loess plateau of Gansu, the natural slope is mostly an earthen one and the RCE on it is very low, only about 0.08 according to testing. The low rainfall (amount in one rain event smaller than 10mm and/or rain intensity smaller than 0.02mm/min), on it cannot produce a runoff, while the runoff produced during rainstorm contains much silt. The less permeable surface of the existing structure is used most widely in Gansu because of its relatively high RCE and lower cost as well as the less silty content. The purpose-built catchment is expensive but for some high value crops or orchards it can be economically feasible. A demonstration pilot in Pengwa Village of Qin’an county showed that, under good management, the input could be returned in a little over two years.

GRIWAC has conducted systematic testing on the RCE of eight kinds of catchment *versus* rain characteristics (rainfall amount and rain intensity). The yearly RCE is shown in Table 1.

It should be mentioned that the yearly mean RCE is the average of event based RCEs in one year. This depends on the weather conditions of the area and during the year. The figures in the table are the test results for Gansu, under which most of the rain during the year was very small rain. For the humid area, since there are more heavy rains and the catchment surface is usually wetter than that in Gansu, the RCE is much higher. The *China National Technical Code of Practice for Rainwater Collection, Storage and Utilization*, gives RCE recommendations for different kinds of catchment in the semi-arid, sub-humid and humid areas.

With the help of the RCE in Table 1, it is possible to calculate the area of catchment necessary for collecting enough rainwater to meet the water demand. GRIWAC has developed a procedure for dimensioning the catchment area and the storage capacity with certain water supply reliability, which is taken as 90 per cent for domestic supply and 75 per cent for supplemental irrigation. Reliability refers to the percentage of years in which the water demand can be fully met.

### Storage subsystem

The storage subsystem consists of the storage tank and the subordinate structures. In Gansu, the most commonly used tank is *Shuijiao*, a traditional underground tank that has been used for thousands of years. The reasons for adopting the underground tank are:

- It is able to collect runoff not only from the roof but also from the ground;
- It can avoid and reduce evaporation loss to the greatest extent;
- Water located 1.5m under the ground has a low temperature, which helps maintain good quality;
- It can avoid freezing of the water during winter time. In the loess plateau of Gansu, the lowest temperature can be dropped down to -20$^o$C. A surface tank with an open top is not practicable; and

- In many parts of the area, the local loess soil can keep stable in a vertical cut with a height of 10m or even more without any support in case the soil is dry. The underground tank can make full use of the "self-stable" feature of the soil, thus saving a lot of construction materials.

The *Shuijiao* has a bottle-like shape with larger depth and smaller diameter, (Figure 1). The ratio of depth to maximum diameter is usually 1.5 to 2. A traditional water cellar has three parts: the tank opening, the "dry part" and the "wet part". The tank opening is located above the ground. It has a diameter of 0.8-1 m and a height of 0.6-0.8 m and is built of brick or stone. The dry part of the tank is usually not for storing water. It has the shape of a hopper and is the transition section from the large inside diameter of 3-4 m to the opening diameter of 1 m. The above property of loess soil ensures the stability of the soil hopper if the slope is flatter than 1:1. The wet part is used to store water. The bottom is flat or in the shape of an inverted arch. The essential factor for the success of the water cellar is to have a watertight layer to stop any infiltration from the stored water into the soil. Earlier, the material used to control seepage was a straw clay mud layer of thickness 3 cm. However, the method to paste the straw clay mud is very complicated and labour-intensive. Often the mud layer cracks and seepage occurs; wet soil subsides and the cellar collapses.

After studying the experiences of the local people in building *Shuijiao,* the GRIWAC made improvements in the design and construction of the water cellar. First, to save labour and time and also to ensure construction quality, cement mortar of grade M10 of the same thickness has replaced the clay mud. Besides, when the soil is not firm enough to be stable with its own strength, then additional structural support is necessary. Figure 2 shows a water cellar with a cement mortar pasted wall and a concrete dome structure developed by GRIWAC. This kind of cellar structure ensures a more reliable water cellar and many of them have already been operating for 20 years.

The subordinate structures of the storage subsystem include the sediment tank and the filtration facility.

**Figure 1: Traditional water cellar (*Shuijiao*)**

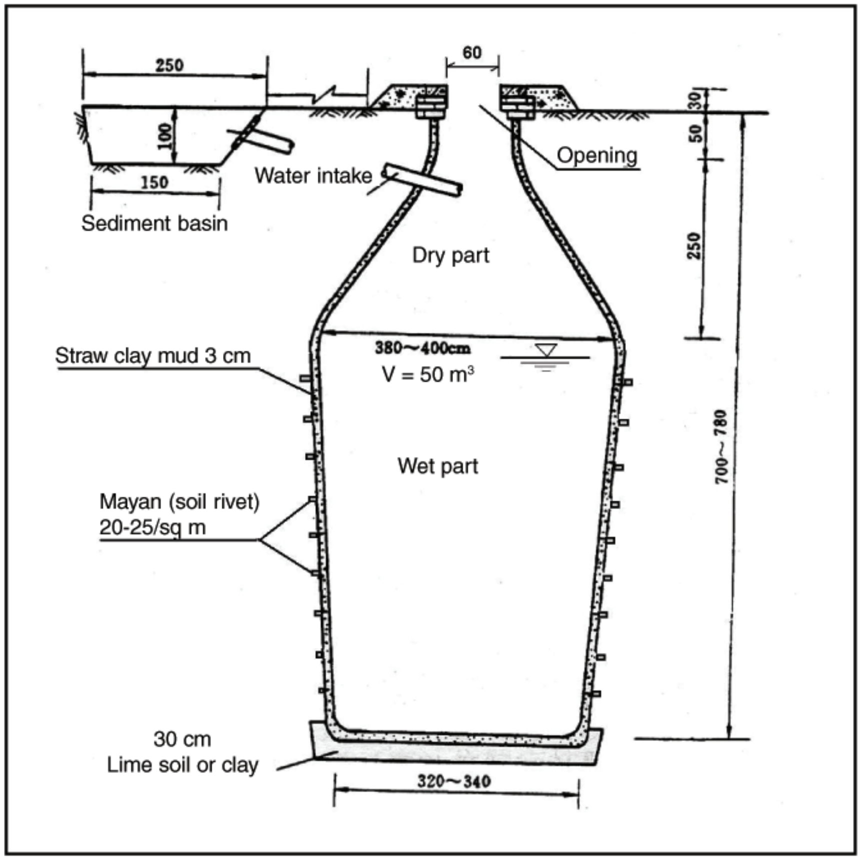


**Figure 2: Water cellar with cement mortar pasted wall and concrete dome structure**

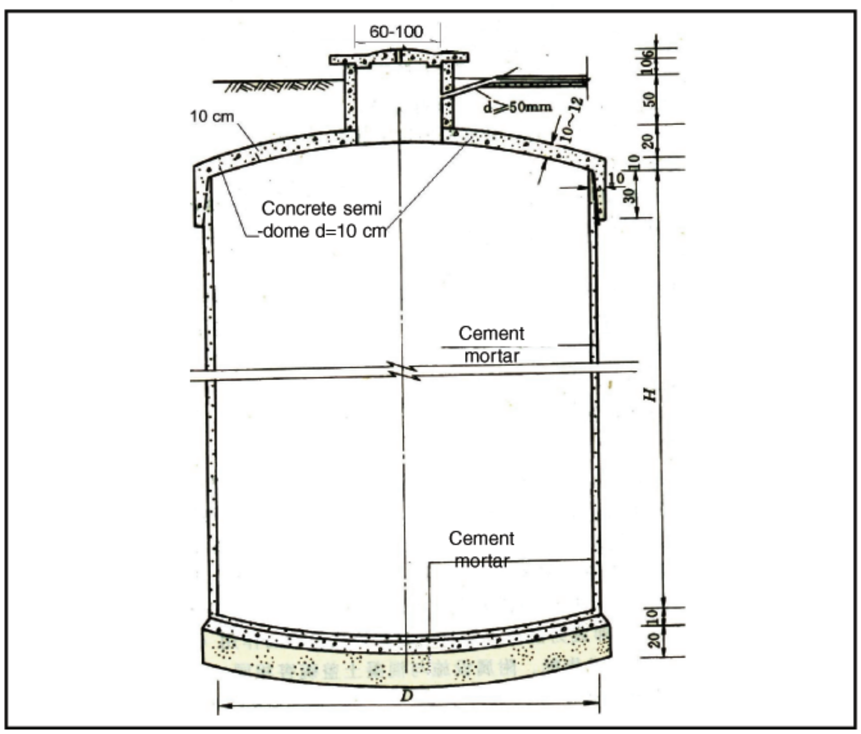

**Figure 3: Hand pump and solar heater in a household RWH system**

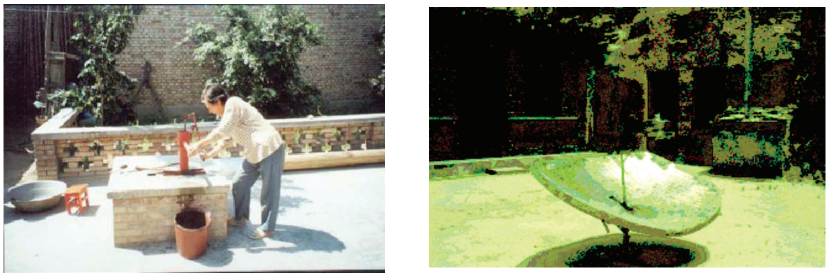

**Figure 4: RWH irrigation system using highway as catchment and drip with rainwater tank**

The sediment tank is used in case the catchment has a natural slope or some other earthen surface. The filtration facility is a small tank with gravel and sand placed layer by layer. The non-woven geomembrane wrapped outside an intake pipe of the tank can also be used as a filter.

#### Water supply and irrigation subsystem

At first, a simple bucket with a rope was used for fetching water out of the water cellar. As hand pumps gradually became cheaper, they increasingly replaced the bucket (Figure 3). Some households used an electrical submerged pump to set up a simple tap water system.

Water quality is a big problem. Monitoring during 1991 and 1992 indicated that the biological indexes (number of bacteria and *coli* form) could not meet the national standard on drinking water quality. GRIWAC suggested that local inhabitants adopt several measures, including using the first flush, adding chemical agents and boiling water before drinking. However, the rainfall in this area is so rare that the farmers cannot anticipate how long the rain will last or when the next rain would come; and so they do not want to waste a drop of water. Thus the first flush has not been accepted. As for adding chemicals, local people do not like the smell and taste and so they seldom practised this method. Drinking boiled water is better accepted because local people, like most Chinese, have the habit of drinking tea.

To avoid destroying vegetation, the Lanzhou Solar Energy Institute has developed a simple solar heater. It can boil 2.5-litres of water within 20 minutes under sunshine. A set costs only about US$ 15, and so is acceptable to most households (Figure 3). The solar heater soon became available in the market. Now in the Dingxi District, an area well known for its dry and impoverished conditions, there are five workshops producing the solar heater, each with a capacity of 50,000 sets per year. But even when the family has a solar heater, the farmer still does not boil water often enough for drinking. Fortunately, so far there have been no reports of diarrhoea or other water-borne epidemic diseases.

For the RWH irrigation subsystem, highly efficient methods have been developed. The water stored in the tanks is in very small quantities and therefore should be used very efficiently. The first principle adopted is that of insufficient irrigation (limit irrigation). That is, the crop water demand will not be met fully but only partially to maximize the productivity of the rainwater. In other words, the crop yield per drop of rain should be maximum. Irrigation is done only at some critical points of the crop growth period and is applied in a limited way. Second, the irrigation quota is very small compared to conventional irrigation. Water is applied only at the root zone of the crop. As the farmers say, we are watering the crop, not the field. Third, efficient, water-saving irrigation methods have been used. To reduce evaporation losses from the soil, the land is covered with plastic sheets. There are indigenous innovative methods, like irrigation through holes in the plastic mulching, injection irrigation and manual bunch irrigation, for instance. The most efficient way is to irrigate during seeding. While sowing, a vessel is mounted on the seeding machine and a tube introduces a small amount of water from the vessel to the seed drills. A special machine has been developed which will lay plastic sheeting while drilling seeds and applying fertilizer and water to help germination. With 3-5 m/Mu of water application during seeding, the germination rates can be up to more than 90 per cent, compared to 50-70 per cent without irrigation. Modern mini-irrigation methods like drip, micro-spraying and bubble irrigation (mainly for orchards) are also used. Figure 4 shows the RWH irrigation system, using the highway as catchment, and drip irrigation with a rainwater tank.

## Experiences and problems

#### RWH is sustainable

The RWH system developed rapidly and has played a great role in social and economic development over the past 20 years in the loess plateau. RWH can provide reliable, clean and cheap water supply at household level to meet basic human needs. Although the supply is still low, the RWH domestic water supply is warmly welcomed by the local people. With the RWH system, the water supply situation has dramatically changed. Farmers say the distant, dirty and bitter water of the past has now been substituted by nearby, clean and sweet water. A study shows a family of five can save on average 70 labour-days per year for fetching water. In the past, water was carried mostly on women's and children's shoulders. RWH rid them of this hard labour.

The progress of RWH irrigation has also been effective in enhancing agricultural production. Tests show that, although the water applied to the crop is in very limited quantity, its effect is significant. With RWH irrigation, crop yield can be raised by 20-88 per cent and 40 per cent on average, compared to the simple rain-fed one. Moreover, with the water in the tank, farmers can now grow cash crops that were impossible to plant prior to the RWH project for lack of water. This has greatly helped farmers in income generation and poverty alleviation. As one of the results of the RWH project, since the 1990s, numerous greenhouses irrigated with *Shuijiao*s have come up in the mountainous areas. Statistics show that, by the end of 2007, about 27,000 ha of greenhouses (each of area 300-400m$^2$) were built during the RWH development. A greenhouse can have 2-3 harvests of vegetables. The investment on infrastructure can be recovered within one or two years if the product meets the market need.

Fruit production is one of the main industries in this mountainous area. However, in the past it often suffered from drought, and hence from low yield and inferior quality. With RWH irrigation, orchards have rapidly developed, with high gains. An RWH demonstration project in the Pengwa village of Qin'an County with 4,800 m$^2$ of concrete-lined catchment on a hilltop and 40 tanks of 40m$^3$ capacity each were built to irrigate 8 ha of orchards. The total investment was US$ 27,000 while the benefit was US$ 12,000. Recovery took little more than two years.

With an increase in crop yield, farmers began to diversify their production activities. At the end of the last century, the State Government initiated a "land conversion" programme, which encouraged farmers in western China to shift their cultivated land on the steep slope to tree and grass planting. As food production grew, farmers started feeling secure about their food supply. They no longer focussed on land reclamation and instead become motivated to participate in this programme under the favourable policy.

**Figure 5: RWH for planting tree**

The RWH is essential in helping young trees survive. Figure 5 shows young trees being irrigated by drip lines with rainwater; and deep pits to concentrate rain for tree planting. RWH has played an important role in recovering the ecosystem and conserving the environment in this semi-arid mountainous region.

To sum up, the 20-year experiences of RWH development in Gansu China indicate that RWH is not only a temporary measure to mitigate drought but also a strategic measure for the sustainable and integrated rural development in this dry, mountainous area.

### Acceptance of RWH

The RWH approach has been well accepted by the rural people. In addition to its high benefits:

- Household ownership of the RWH system is key to the high motivation of the farmers. Unlike the key water projects, invested and owned by the State or big enterprises, the decentralized RWH systems belonged to the households themselves. When the project completed the household gets a certificate of ownership, which becomes an important part of the household's estate.
- The investment required for the RWH system is affordable to both the farmers and the government. The farmers contribute about two third of the total investment, mainly in the form of labour and local materials for construction. The high profits gained from the RWH system can recover the investment in a short period.
- RWH has become a local tradition and has been updated with appropriate modern technology. With little or no assistance from village technicians, most farmers have the capacity to build the RWH system by themselves. The decentralized approach of the RWH project suits the natural and social conditions of this mountainous and impoverished area.
- Proper preparation, organization and management of the project implementation are also important success factors. From the very beginning, GRIWAC helped thousands of "scientific households" to build RWH systems that provided good examples for the general population and also for the politicians. Technical guidance and training courses at different levels were also essential elements in project implementation.

### Problems

Although great progress has been achieved in the past two decades, there are still problems to be tackled.

- The water supply can only meet basic human needs: drinking, cooking, animal and poultry raising and, to a limited extent, for washing. The water supply level needs to be increased. To enlarge the RWH system, both the catchment area and the storage capacity need to be enhanced in the future. The government needs to give even more support to rural households to develop their RWH system.
- The water quality has to be improved. Households have been advised to build two tanks: one for storing

roof runoff and the other for storing ground runoff. The former can be used for cooking and drinking. Quality enhancing facilities - like the first flush device, a gutter and down pipe and filtration equipment - have to be added to the system. Health education for farmers has to be strengthened.

- The RWH irrigation schemes have not yet been fully exploited. Many rainwater tanks full of water for irrigation have not often been used. One reason for this is that farmers cannot afford to buy an irrigation facility. Another reason is that the idea of irrigation with rainwater is still less accepted by farmers than the domestic RWH. Awareness building and know-how training is still necessary.
- The main problem is that recognition of the RWH approach in the water resources community is still less than that of surface and groundwater development. The RWH has not yet gained its due position in the integrated management of water resources (IWRM).

## References


1. Ministry of Water Resources: 2001, "Technical Code of Practice for Rainwater collection, Storage and Utilization", China Water Resources and Hydro Power Press, Beijing. (in Chinese).
2. Zhu Qiang, *et al*, Chief edited and co-written, 2007, "Rainwater Harvesting", Anhui Educational Publishing House, Hefei.
3. Zhu Qiang, *et al*, 2006, "Rainwater harvesting: The key to sustainable rural development in Gansu, China", *Waterlines*, Vol. 24, No. 4, Intermediate Technology Publications.
4. Zhu Qiang *et al*, 2003, "Rainwater harvesting and poverty alleviation: a case study in Gansu China", *Water Resources Development*, Vol. 19, No. 4, Carfax Publishing.
5. Zhu Qiang, *et al*, 2000, "Rainwater harvesting for survival and development", *Waterlines*, Vol. 18, No. 3, *Intermediate Technology Publications*.
6. Zhu Qiang, *et al*, 1995, "A lifeblood transfusion: Gansu's new rainwater catchment systems", *Waterlines*, Vol. 14, No. 2, Intermediate Technol-