Plenty4All

Rainwater Harvesting System

www.plenty4all.net

Introduction

Rainwater running off land surfaces can be harvested, stored and utilized using a technique called ***rainwater harvesting*** instead of being wasted in rivers, lakes and the sea.

Rainwater harvesting consists of 5 components:

1. **Rainfall**
2. **Catchment areas**, also called watersheds, onto which the rainwater falls.
3. **Gutters**, or conveying channels, to bring rainwater from a catchment area to storage reservoir.
4. **Storage reservoirs** can be tanks, ponds, dams and in situ storage in sand and soil.
5. **Retrieval** water is extracted from **reservoirs** either by gravity or by pumps and lifts.

A rural homestead should preferably have the following variety of structures for harvesting rainwater to avoid water shortages during dry seasons:

1) A **roof catchment system** for clean domestic water that consists of gutters fixed to the roof which drain the rainwater into a storage tank. The size of a storage tank depends mainly on the financial capacity of the owner and to a lesser degree on the size of the roof and the volume of rainfall. However, the ability to supply sufficient water during years with drought depends on the size of the roof and the tank.

2) A **pond or an earth dam** for watering livestock and garden irrigation can be excavated by hand or animal drawn implements at a low place in the farmland where rainwater flows, or accumulates, during rainy seasons. Ponds and dams can initially be built small and enlarged during the following dry seasons until they might supply water throughout the years.

3) A **hand dug well** may supply water if sunk into shallow ground water, e.g. downstream of an earth dam or near evergreen trees growing on riverbanks.

In situ harvesting of rainwater in farmland increases the yield of crops and will often determine whether there will be anything to harvest at all. Most farmers know and apply some of the techniques of soil conservation that make rainwater percolate into the soil instead of eroding the farmland. Among several techniques, the following are being used by many farmers:

1. Contour planting in horizontal ploughing lines.
2. Contour trash lines with grass and farm waste.
3. Contour ridges that develop into terraces.
4. Contour bunds of stones that develop into terraces.
5. Bench terraces that develop slowly from contour ridges.
6. Micro catchments with U and V shaped soil bunds for growing grass and crops and trees.
7. Trapezoidal bunds with a farming area of 1,350 m2 (1/3 acre) for grass and crops.
8. Cut-off drains to discharge surplus rainwater run-off into gullies with check dams and streams.
9. Check dams of stones and vegetation to heal eroded gullies.
10. Check dams of stones and vegetation in valleys.

The water cycle

Every living creature and vegetation must have water in order to survive.
Only 3% of all water on Earth is fresh water and 68% of the water is frozen ice on the North and South Poles. All humans and most animals as well as nearly all vegetation can only survive on fresh water free of salt and minerals. Water for irrigation must also be fresh water and applied sparingly by flood, furrow or drip irrigation, otherwise the irrigated soil will turn saline and unproductive for many years to come.

The other 97% of the water on planet Earth is saline seawater in which whales, fish, corals and plankton flourish. Slightly salty water may be used for watering livestock and other animals, although fresh water is healthier.

Nearly half of all deep boreholes are dry or contain saline (brackish) water with minerals harmful to humans, animals and plants. Where fresh water is pumped up from very deep boreholes it is called mining fossil water because the water withdrawn cannot be replaced by rains.

Therefore, there are only two sustainable solutions to the world's increasing demand for water, namely rainwater harvesting and water conservation.

Fresh water sources are replenished in a water cycle through the following activities:

1. Evaporation is an almost invisible vapour rising from water surfaces.
2. Transpiration is evaporation from vegetation and soil surfaces.
3. Precipitation from clouds falls as fogs, mists, rains, hails and snow.
4. Rainwater run-off is rainwater running off all kind of surfaces.
5. Drainage is the ability to drain excess water away from catchments.
6. Infiltration is the movement of water into the soil from the surface.
7. Percolation is the movement of water through the soil to the underground layers.
8. Permeability is the rate at which water penetrates through soils down into the underground water table.
9. In situ storage is storage of water in the voids between particles of soil and sand.
10. Subsurface flow is a flow of water in the voids of soil and sand particles.

Water can be harvested at several stages in the water cycle, such as:

1. Fog screens placed on hills, mountains and near the sea for domestic water.
2. Gutters attached to roofs for domestic water.
3. Garlands of stone gutters on rock outcrops for domestic water.
4. Soil bunds and trenches on farmland for crops and animals.
5. Diversion trenches from roads, rocks and hillsides for seasonal flood irrigation.
6. Hand dug wells in shallow ground water to supply water for all uses.
7. Subsurface dams, weirs and sand dams to increase the yield of hand dug wells situated along seasonal water courses.
8. Boreholes drilled into deep ground water where none of the above options are replicable, although expensive and only 40% may not supply fresh water.

The quality of water from all these sources can be tested by either a portable testing kit or by a laboratory if the samples can be delivered before deteriorating due to heat over long distances. Contaminated water may be treated by several methods, such as SODIS (Solar disinfection), boiling, water filters, crushed seeds from the Moringa tree, ultra-violet rays (UV) or artificial chemicals.

Rainfall

Although it is known that clouds can be seeded with chemicals to produce rains, the practice is expensive and unsustainable. It should therefore be realized that rainfall varies from region to region and from one year to another beyond peoples' manipulation and interference.

All fresh water comes from rains, including water in deep boreholes which originates from rains infiltrated into the underground thousands or millions of years ago. Fresh water can only be obtained from four main sources; rainwater harvesting, shallow ground water, deep ground water and desalination of which the two latter options are too expensive to be discussed here.

The North-East monsoon coming from India brings rains to East Africa from October to December every year. The South-East monsoon brings rains from March to June. Rain falls where and when the two monsoons meet. The area of convergence is called the Inter-Tropical Convergence Zone. This zone follows the apparent movement of the sun, north and south, bringing rain in its wake. But the pattern is influenced by mountain ranges, Lake Victoria and periodic westerly winds from the Atlantic.

The two monsoons bring an annual average of about 600 mm rainfall to the semi-arid eastern and northern parts of Kenya, while the highland zone at Mount Kenya has a mean average of 1,000 mm and the Lake Victoria zone has a mean average of 1,800 mm. The rainfall pattern of East Africa is also presented as a map with different colours for the various average annual rainfalls.

Catchment areas

Run-off from catchment areas

Although regions with low and erratic rainfalls appear to be unsuitable for rainwater harvesting, it has been proved many times that rainwater harvesting is the most viable water supply system in arid and semi-desert regions. Rainwater harvesting in dry regions is viable when the following aspects are considered and applied:

1. Catchment areas are enlarged to increase the volume of run-off water.
2. Storage reservoirs are made large to store more water for longer periods.
3. Evaporation is minimized by roofing storage reservoirs.
4. Underground water storage in situ in the soil of farmland and sand of riverbeds.

The following two examples show that rainwater harvesting is viable in regions with little rainfall provided the catchment area is enlarged accordingly:

Example1. A roof with a catchment area of 100 square metres (m^2.) and an annual rainfall of 800 millimetres (mm) can supply 72,000 litres of water (100 m^2 roof x 800 mm rain = 80,000 litres minus 10% loss = 72,000 litres).

Example2. A roof in semi-desert regions with an annual rainfall of 200 mm has to be 4 times l arger to supply an equal volume of 72,000 litres of water, because the rainfall is only 1/4 of the 800 mm rain shown in Example 1.

To design successful rainwater harvesting systems, it is important to know:

1) How much rainwater falls on a catchment area.

2) How much of the rainwater runs off the catchment area.

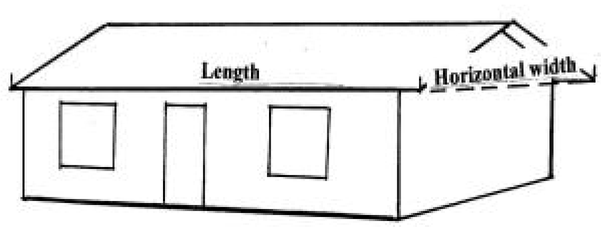
If these two figures are not known, the storage capacity of a water reservoir and its spillways cannot be designed properly. The ruins of such improperly designed water projects can be witnessed in most parts of Africa.

The size of a catchment area is measured in square metres (m^2) or in hectares (ha). 1 ha consists of 10,000 m^2 which is equal to 2.47 acres. An acre is equal to 4,047 m^2.

Farmers measure their acreage of land by walking 70 paces, each pace with a length of 3 feet, equal to 0.915 metre, around the four sides of a square. 70 walking paces x 0.915 metres are equal to 64.05 metres.

When two sides of the square are multiplied with each other the result is 4,102 m^2 (64.05 x 64.05), this is close to the actual area of 4,047 m^2 for 1 acre.
When the size of a catchment area and the volume of rainwater falling on that catchment area have been found, the volume of rainwater that can be harvested is be calculated by multiplying the length with the horizontal width of the roof.

For example: Length 20 m x horizontal width 5 m = 100 square metres



A sketch showing the length with the horizontal width of a double pitched roof

Farmers may admit: "Okay, it has rained but it was only a drizzle". Nevertheless, a drizzle of 10 mm rain can be sufficient to produce the required volume of water, if the catchment area is sufficiently large. The relationship between rainfall and catchment area can be explained by the following example:

A drizzle of 10 mm rain on10,000 m2 (1 hectare = 100 m x 100 m) area of a roof, rock or tarmac road, it produces 100,000 litres of run-off water minus about 20 % loss = 80,000 litres.

- 10 mm rain x 10,000 sq.m. minus 20% loss = 80,000 litres.
- If the same drizzle of 10 mm rains falls on a ten times larger catchment area of 100,000 sq.m. (10 hectares = 100 m x 1,000 m,) it produces ten times more water, namely 800,000 litres x 10 = 8,000,000 litres of water = 8 million litres = 8,000 cu.m.

A pond for a catchment area

Therefore, a drizzle of 10 mm rains may be sufficient for harvesting a required volume of water, if the catchment area is large enough. Huge volumes of water can thus be harvested from e.g. roads because they have large and hard surface catchment areas.

For example: a drizzle of 10 mm rain on a road 6 metres wide and 1 km (1,000 metres) long road can supply the following volume of water: A 6 m x 1,000 m road x 10 mm minus 20% loss = 48,000 litres = 48 m^3 of water.

Run-off water from a tarmac road.

When designing a reservoir to hold water from a road catchment it is important that spillways can discharge safely the overflowing water during storms.

For example: A rain storm of 75 mm falling on a 2 km long road produces about: 75 mm rain x 6 m x 2,000 m road minus 20% = 720,000 litres = 720 m3 of water.

If the storage capacity, such as a pond is 500 m^3, then the spillways must be capable of discharging 220 m^3 of water (720 minus 500) in a few minutes or the pond will be damaged or perhaps washed away by the flood of incoming water.

Catchment of rainwater from roads is potentially the cheapest water source in dry-land where there are no sandy riverbeds (luggahs). Tarmacked roads produce more run-off water than dirt roads but the water may contain harmful tar components for people and livestock and should therefore be used for irrigation only.

There are two main types of storage, namely:

1. Storage in reservoirs, such as ponds, earth dams and tanks.
2. Storage in situ, that is in the voids between particles of soil and sand.

Evaporation, Seepage and leakage

Almost every type of storage reservoir loses some of its stored water to evaporation, seepage or leakage.

Evaporation losses

Open water reservoirs, such as; tanks without roofs, ponds, earth dams and rock catchment dams, lose water due to evaporation. In hot and windy climates the evaporation rate may be over 3 mm per day which is equal to losing a depth of 0.9 metre of water in a month. Water tanks and rock catchments should therefore be roofed but that is not feasible for ponds and earth dams.

Rainwater stored in the voids between the sand particles of riverbeds is the most economical water storage because up to 350 litres (35%) of water can be extracted from 1 cubic metre of coarse sand while only about 10% of water can be extracted from fine structured sand because its voids are smaller.

In hot regions without sandy riverbeds, rainwater can be stored in situ between the voids between soil particles, e.g. downstream of ponds and earth dams or in terraced land or in seasonal macro and micro irrigation structures as described in "Water Storage".

Seepage losses

In addition to evaporation loses, water stored in ponds and earth dams also lose water to seepage through the floor of these reservoirs. Fortunately, some of the seepage loses from ponds and dams can be utilized by sinking a shallow well into a seepage area. However, the combined losses of seepage and evaporation during long dry seasons usually result in the ponds and earth dams drying up except for very large earth dams.

The seepage loses through the floor of ponds and earth dams can be partly sealed by either:

1. Covering the floor with clayey soil or cow dung followed by cattle driven over the floor for compaction.

2. Waiting for several rainy seasons to deposit layers of silt. Seepage losses from sand in riverbeds can be avoided if proposed construction sites with boulders and fractured rocks are rejected.

Leakage losses

Loss of water from leaking water tanks, water pipes, water taps should be prevented by using either bitumen paste or cement mortar.

Gutters

Many rainwater harvesting installations do not perform as well as expected because of unsatisfactory gutters. It is therefore important to give careful attention to the materials used, the way the gutters are fabricated and the way they are installed. Ways of fabricating and installing low-cost gutters are described below.

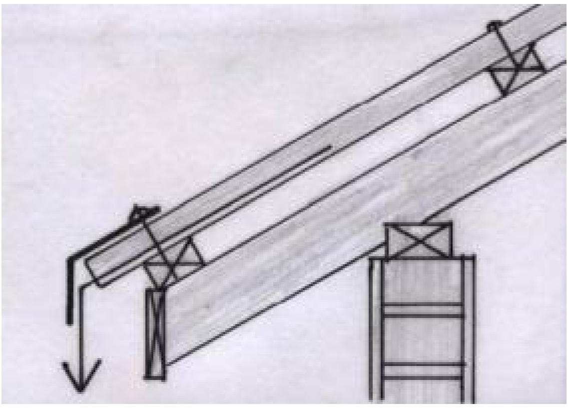
Semi-circular gutters

The best known gutter is semi-circular and made either of galvanized iron sheet or PVC. Gutters are laid in gutter brackets nailed onto facia-boards or in V-shaped tree branches nailed to the rafters with a gradient sloping towards the water tank. Bamboo and Sisal poles can also be used as gutters when split in two halves.

Simple and cheap gutter laid in tree branches

Gutter suspended with a straight slope from a splash-guard nailed onto an uneven roof

Splash-guards


A **splash-guard**, a strip of galvanized iron


Marking an iron sheet into three stripes with a wire


Bending the edge of an iron sheet

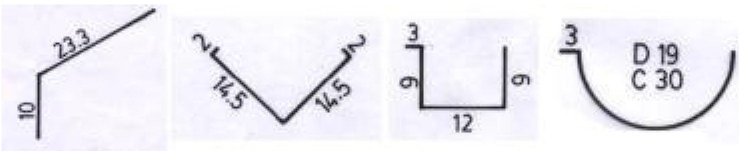
They prevent rainwater from over-shooting gutters. They are made of strips of iron sheets bent at an angle and nailed onto the roof. Gutters are suspended with from the splash-guard using galvanized wires.

How to make and install Gutters with Splash-Guard

Cut galvanized plain iron sheets of gauge 26 or 28 into three strips, each being 200 cm long and 33.3 cm wide by marking the sheets with a thick wire, about 40 cm long, with each end having a sharp bend and a pointed end to scratch a line. The distance between the two bends must be 33.3 cm in order to make equal width of the cut sheets.

The metal strips are bent over a U-shaped piece of iron and hammered into shape with a piece of wood or a mallet.

The shape of the metal strips depends on whether they shall be splash-guards or gutters with one of the shapes shown below: namely the V-shaped gutter, the square gutter and the semi-circular gutter.



From left to right: **Splash-guard; V-shaped gutter; square gutter and semi-circular gutter**

V-shaped gutter suspended from a splash-guard.

Square gutter installed without splash-guard

Gutters are fitted into hangers made of 3 mm galvanised wires that are bent over nails hammered into a piece of wood.

Gutters are fitted into hangers made of 3 mm galvanised wires that are bent over nails hammered into a piece of wood.

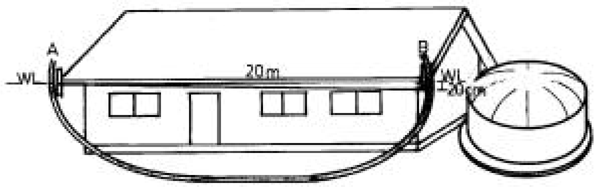
Gutters fitted into hangers tied to a splash-guard nailed onto an uneven roof

How to install Gutters

Gutters should be installed with a gradient of 10 cm depth for every 10 m length of a roof. This gradient of 1:100 will facilitate rain water running off the gutter with high velocity and no water will be wasted due to overflow. The high velocity of the water will transport leaves and debris to the inlet sieve without blocking the gutter.

Splash-guard being nailed into a roof

Water level in a hosepipe filled with water



The two water levels in the hosepipe filled with water gives an exact horizontal level

A gutter hanger is tied to the splash-guard with its bottom at the level of the water in the hosepipe. A second hanger is tied to the other end of the splash-guard near the tank. This hanger is tied to the splash-guard with a slope 1:100 below the water level in the hosepipe.

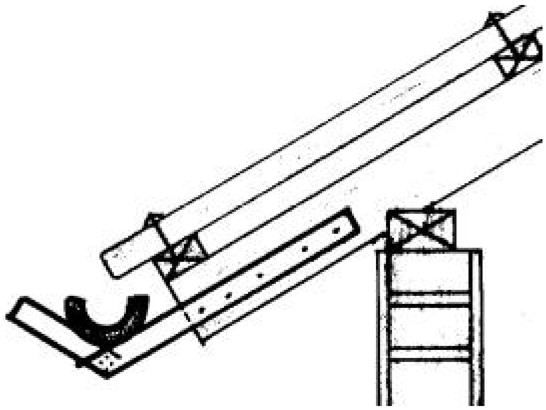
A gradient of 1:100 is distance is found by dividing the length of a roof with a factor of 100. For example; if a roof is 20 m long, the hanger at the water tank must be 20 cm lower than the other hanger to get the desired gradient of 1:100.

The first gutter laid along a drawn string

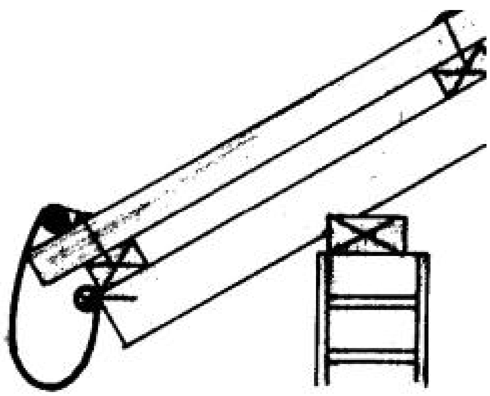
Gutter laid in hangers

Two hangers are attached to the first gutter with one hanger at the middle and the other hanger at the end of the gutter. Bitumen is smeared on the inner end of first gutter before a second gutter is laid into it and so on until the whole length of gutter is installed.

Other Types of Gutters



PVC pipes or Bamboo cut in half can be laid in timber or branches nailed onto the rafters.



One side of galvanised and corrugated iron sheets can be nailed to the rafters, while the sheets are held in position by galvanized wires tied to the roofing nails.

Storage Reservoir

The required storage capacity of a water reservoir depends on:

1. The daily required volumes and quality of water measured in litres.
2. The length of the dry seasons during which these volumes and quality of water are required.

Example on water demand for a homestead:

While the number of days in a dry season can be estimated fairly easy, such as 180 days without rain in a semi-arid region, the volume of water required for each of the 180 days can be calculated using the following guidelines on daily requirements of water for a rural homestead:

Water users	**Daily requirements** Litres	**Number of days without rains**	**Required volume for a dry season** Litres
1 person	15	180	2,700
1 grade cow	50	180	9,000
1 local cow	20	180	3,600
1 goat	5	180	900
1 sheep	5	180	900
1 hen	0.3	180	54
3.3 mm on 4048 m^2 (1 acre) with drip irrigation	1,336	60 days x 1,336	80,150
5 mm on 4048 m^2 (1 acre) with furrow irrigation	2,024	60 days x 2024	121,440
4.3 mm on 4048 m^2 (1 acre) with sprinkler irrigation	1,741	60 days x 1741	104,460

A homestead with 6 persons, 4 local cows, 20 goats and sheep (shoats) and 20 hens who wants to irrigate 2023 m^2 (1/4 acre) with drip irrigation requires the following volume of water for a 180 days dry season without any rains:

	Litres
Clean water from roof for domestic use: 6 persons x 2,700 L	16,200
Unclean water from a water hole in a riverbed: 4 cows x 3,600 L	14,400
Unclean water from a water hole in a riverbed: 20 shoats x 900 L	18,000
Unclean water from a ground tank or a pond: 20 hens x 54 L	1,080
Unclean water from a ground tank or a pond for irrigating 1/4 acre: 80,150 x 1/4	20,038
Total storage requirement	**69,718**
Add 20% loss due to *evaporation* and seepage	13,944
Total storage requirement for a 180 day long dry period	**83,662**

This example shows that a rural homestead in a dry area could use 3 types of water sources:

1) A roof catchment tank with a storage capacity of at least 16,200 + 20% loss = 19,440 litres for fresh clean water for domestic use.

2) A well in a riverbed or a pond that can supply 14,400 + 18,000 + 1,080 + 20% loss = 40,176 litres of unclean and, perhaps, saline water for the livestock.

3) A ground catchment tank or a pond that can supply 20,038 + 20% loss = 24,046 litres of fresh but unclean water for drip irrigation.

Introduction to Shallow Ground Water

Ground water is rainwater that has percolated into the underground. There are two main types of ground water, namely:

1) ***Shallow ground water*** that can be reached by means of hand dug wells in areas where rainwater has been trapped in the underground such as in valleys, downstream of earth dams and near swamps, seasonal water courses, rivers and lakes.

2) ***Deep ground water*** is rainwater that has percolated deep into the underground during centuries or thousands of years.

This water source can only be reached by drilling deep boreholes from where water is extracted using electric powered submersible pumps that deliver water to storage tanks. Recharge of rainwater to deep boreholes may take hundreds of years. Most deep boreholes do therefore suffer from sinking water levels or high salinity of the water before they finally may run dry. Due to these constraints and the high cost of construction, operation and maintenance of deep boreholes, this subject is not considered relevant for this website.

Often shallow ground water can be found in valleys, downstream of earth dams, along seasonal water courses, rivers and near swamps and lakes.

Water for domestic use watering livestock and garden irrigation can be drawn from hand dug wells sunk in shallow ground water. Hand drilled boreholes using a simple drilling rig can also be used for reaching shallow ground water.

Sinking of shallow wells is the most economical solution to construct a good water supply for homesteads and communities, provided fresh ground water can be found within a depth of maximum 20 metres. Shallow water may be found in the following locations:

- In riverbanks along permanent rivers and seasonal water courses such as sandy riverbeds, luggas, wadis and other ephermeral water courses
- In seepage areas downstream of pans, ponds and earth dams
- In seepage areas next to lakes, swamps and underground springs
- In valleys
- At foot slopes of large hills and rock outcrops. Usually, water from wells downstream of earth dams can be used for domestic purposes because the dirty water from the upstream dam has been cleansed by seeping through the underground. Livestock should be watered from a well situated downstream of the dam reservoir instead of drinking directly from the reservoir because the animals will contaminate the water and may cause erosion to the dam.

Identifying Places with Shallow Ground Water Tables

Since time immemorial, riverbeds have provided water for people and animals. During extreme droughts, when all other water sources have dried up, water can still be found in riverbeds. Elephants, ant-eaters and some other wild animals have a special sense by which they can locate such places where water is found. Some rural people and most well-diggers also know that water can only be found at certain places. They may also give a rough estimate on how deep they have to dig before reaching the water-table. Their knowledge is based on the fact that certain species of trees and vegetation must have roots reaching down and into the water-table in order to survive droughts. This traditional information is compiled in the table below.

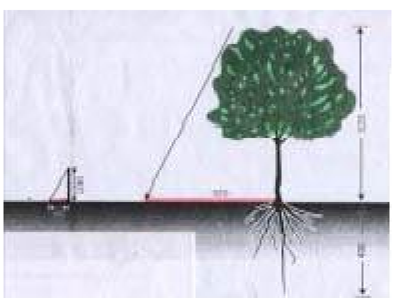
Techniques for identifying places with shallow water tables are:

1) Water-indicating vegetation and trees

Botanical name	**Depth to water level**
Cyperus rotundus	3 to 7 m
Vangueria tomentosa	5 to 10 m
Delonix elata	5 to 10 m
Grewia	7 to 10 m
Markhamia hildebrandtii	8 to 15 m

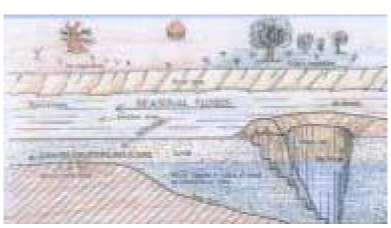
Hyphaene thebacia	9 to 15 m
Borassus flabellierfer	9 to 15 m
Ficus walkefieldii	9 to 15 m
Ficus natalensis	9 to 15 m
Ficus malatocapra	9 to 15 m
Piptadenia hildebranditi	9 to 20 m
Kigelia aethiopica	9 to 20 m
Acacia seyal	9 to 20 m

Since the above mentioned trees must have their tap root in the water table, the depth of a water-table can be found by knowing the depth of the tree's tap root. A rule of thumb states that the tap root of a tree has a depth equal to about 3/4 of the height of the tree. The height of a tree can be found by measuring the length of the shadow the tree is casting on the ground and comparing it with the length of the shadow of a stick 100 centimeters long. The two measurements should be taken in the sunshine of early morning or late afternoon when the shadows are longest.



For example: If the stick's shadow is 80 cm long, the ratio is: 100/80 = 5/4 If the tree's shadow is 12 m long, then the tree is: 12 m x 5/4= 15 m high and the tap root and water level is at: 15 m x 3/4 = **11.25 m depth**.

2) Seasonal water holes



Waterholes in riverbeds

The floors under the sand in riverbeds can consist of soil, clay, murram, black cotton soil, boulders, fractured rocks or solid rock bars

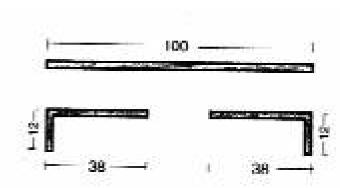
Where floors consist of permeable (water-leaking) material, such as sandy soil, fractured rocks or large boulders, water will seep into the underground through the floor. This may be beneficial for deep boreholes but certainly not for extracting water from riverbeds.

If a floor consists of an impermeable (water-tight) texture, such as clay, clayey soil or murram, there is no leakage through the floor. Water can therefore be extracted from the riverbed, unless it has drained downstream and left the riverbed dry.
Riverbeds have downstream gradients because they function as drainage channels for rainwater run-off. Water in riverbeds is therefore always moving downstream on the surface and between the sand particles under the surface of riverbeds. Surface flow of water can easily be observed during floods but the subsurface flow can only be observed when water is scooped out of waterholes.

The reason why some riverbeds have water and others have not, is because the former have impermeable floors. If riverbeds have impermeable floors but no water, it is because the water has been drained downstream by gravity. If riverbeds with impermeable floors have water,

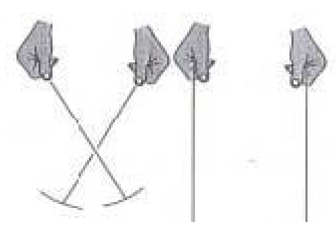
then something must have stopped the water from being drained downstream. What could that be? The answer is found by hammering iron rods into the sand of riverbeds at certain intervals. Such probing shows that most riverbeds have a floor under the sand that bulges up and down. These natural barriers, called dykes, give the answer.Where the floor bulges upwards it acts as an underground dyke that stops the underground flow of water, as seen on probing points no. 10, 13, 15, 19 and 23. Where there is a depression in the floor it accumulates water, as seen on probing points no. 9, 14, 16 and 21. These are subsurface water reservoirs in the sand, from where water can be extracted. Water is found in this waterhole because the dyke prevents the water seeping downwards in the voids between the sand in the riverbed.

3) Dowsing



Dowsing tool

Dowsing tool



Dowsing tool

Gifted persons can use dowsing to locate underground water sources and underground dykes. The tool consists of a 1m long brazing rod cut in two halves and each half having a 12 cm long handle.

How to do: Hold the two dowsing rods loosely and pointing downwards so that they can swing freely. However, the hands must be held steady to allow gravity to pull the rods down while they are parallel. When walking slowly over an unknown underground water source, the rods will swing inwards. The force of the pull indicates the depth and volume of water in the ground. Only certain people have the ability to detect water in this way. Left: here is water; Right: here is no water.

4) Probing in riverbeds

Probing using **probing rods** hammered into the sand

When the most promising lengths of a riverbed have been identified during an evaluation walk, they are probed using probing rods hammered into the sand. The probing data is used for:

a) Drawing a plan and profiles of the riverbed to identify the deepest place from which water should be extracted and the shallowest place where the wall for a subsurface dam, a weir or a sand dam can be constructed.

b) Estimating the volume of sand in the reservoir and the extractable volume of water from the sand.

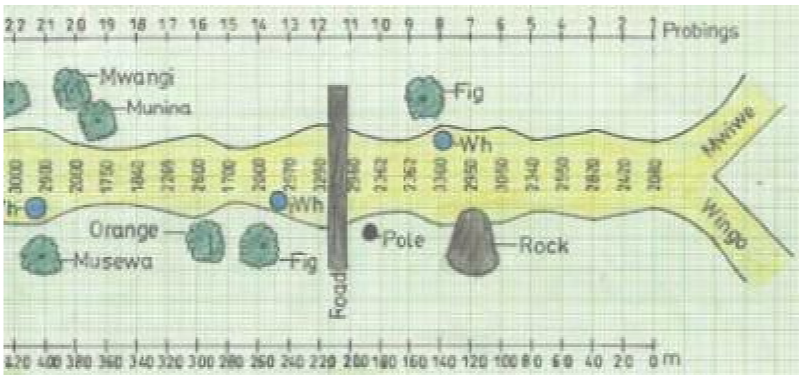
c) Providing the required data for drawing the designs and estimating the costs of construction.

5) Trial pits

Trial pits

Trial pits are excavated down to the floor under the sand every three metres to confirm the correctness of the probing.

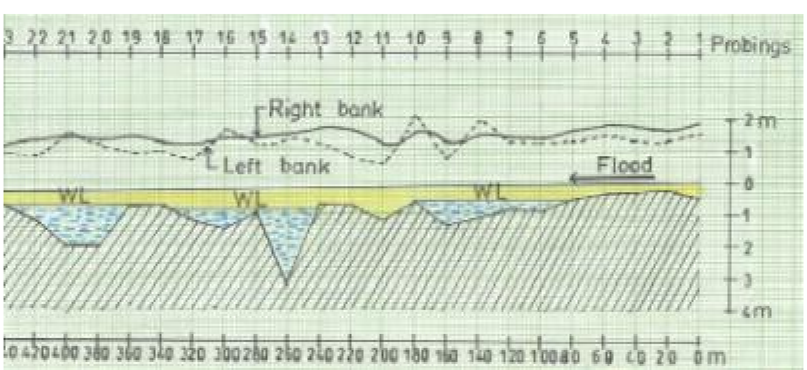
6) Plan and profiles of riverbeds



Plan of the **Ndhiwa riverbed**

Plans and profiles of riverbeds are very useful for identifying places with shallow water tables and volume of extractable water from riverbeds. See for example the plan and longitudinal profile of Ndhiwa riverbed.

A plan and a longitudinal profile was drawn according to the probing data on a sheet of A3 mm graph paper which is 40 cm long and 28 cm wide. The horizontal measurements were drawn to a scale 1:2000, which means that the 440 metres length of the riverbed was drawn as 22 centimetres long and the 20 metre intervals between the probings were drawn as 1 centimetre long on the graph papers.



Longitudinal profile of – **Ndhiwa riverbed**

The plan shows that the probed river has a length of 440 m and width varying from 17.5 m to 33.0 m.

Waterholes having water 7 months after the last rains were located at probing point No. 10, 14 and 21 where the sand is deep. Water is trapped in the sand by downstream dykes at points No. 11, 18 and 23, as see on the longitudinal profile on the right.

The longitudinal profile shows that the sand is 3.0 m deep at point No. 14 and 1.75 m deep at point No. 21. Since both places are holding water 7 months after the last rain they are the best extraction points in that part of Ndhiwa riverbed. The next phase in surveying the riverbed was to probe across at point No. 17 in order to learn of the volume of the depression and its water yielding capacity.

7) Extractable volumes of water from sand in riverbeds

When dry riverbeds are flooded by rains and flash-floods, the air in the voids between sand particles is pressed out by the water because water is heavier than air. When a dry riverbed is being flooded, it looks as if the riverbed is boiling as tens of thousands of air bubbles are being pressed out of the sand. This process is known as **saturation**. Fine textured sand has tiny voids that get saturated slowly with water. About 10% of water can be extracted from the volume of fine sand. Coarse sand has larger voids and is therefore saturated much quicker than fine sand. The volume of water that can be extracted from coarse sand is about 35% of the volume of sand.

Silt and sand extractability was tested and classified as follows:

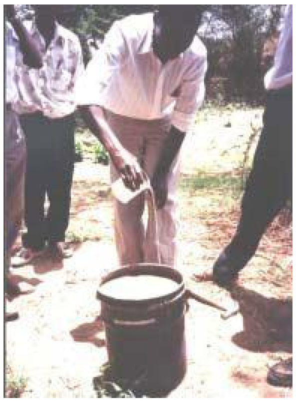
	Silt	**Fine Sand**	**Medium Sand**	**Coarse Sand**
Size (mm)	< 0.5	0.5 to 1	1.0 to 1.5	1.5 to 5.0
Saturation	38%	40%	41%	45%
Water Extraction	5%	19%	25%	35%

Sand testing:

Sand testing

The porosity and the volume of water that can be extracted from the sand reservoir can be determined by saturating 20 litres of sand with a measured volume of water. The water is then drained out of the container and measured by removing a plug from the bottom of the container.

How to do:



Sand test

1) Take samples of dry sand and fill in a 20 litres container.

2) Add water until saturation. For example: If the saturation of the sand was reached after adding 8 litres of water, the saturation is 40% (8 / 20 x 100)

3) Then make a small hole in the bottom of the container to drain the water out of the sand. If, for example, in one hour, 5 litres of water were extracted from the sand, that gives an extractable capacity of 25% (5 / 20 x 100).

Shallow Ground Water

The oldest subsurface dams known were constructed in the almost waterless area around Dodoma, in the Tanganyika and now Tanzania, when the railway was built around 1905. The purpose of the subsurface dams was to provide water for the steam locomotives which they successfully did for many decades.

A subsurface dam was built of soil and documented by Bihawana Mission near Dodoma in the early 1950s and is still functioning well. A similarly successful subsurface dam was built in the same area in the 1920s. Several subsurface dams were built of various materials, such as soil, burnt bricks, concrete blocks and reinforced concrete during a training course in 1991.

Function of subsurface dams

Should the water yield from a river intake or well be insufficient for the demand, then a subsurface dam can be constructed cheaply of soil. The function of a subsurface dam is:

a) Block the underground flow of water between the voids in the sand

b) Raise the water level in the sand to about 50 cm below the surface of a riverbed.

How to construct a subsurface dam

Identifying suitable site

In order to get a maximum volume of water for a minimum of work and investment, the walls of subsurface dams, weirs and sand dams should, whenever possible, always be constructed on underground dykes that are situated downstream of underground water reservoirs, identified by waterholes, water-indicating vegetation, dowsing and probing.

When a suitable site has been identified in a riverbed, the most clayey soil for construction of the dam wall has to be found.

How to identify the most clayey soil:

1) Collect soil samples from nearby riverbanks and fields. The equipment for analyzing the soil samples consists of plastic bottles of equal size, of which the caps have been removed and the bottoms cut off.

2) The bottles are placed upside down in the sand, or sloping against a wall, and filled halfway with soil samples.

3) Water is poured on top of the soil samples several times. After some minutes it can be observed which soil sample has the slowest infiltration rate due to having the highest clay content. This soil is the most suitable for building the dam wall.

Testing soil type to identify most clayey soil

When a suitable site has been identified, all the sand in the riverbed is removed in a 3 metre wide stretch between the two riverbanks, so that the floor under the sand is fully exposed.

Thereafter a 100 cm wide trench, called a key, is excavated into the floor right across the riverbed and into the two riverbanks. The depth of the key must be at least 60 cm into solid soil to prevent seepage under the dam wall.

The best clayey soil identified by the testing mentioned above, must now be transported to the dam site by e.g. sacks, donkeys, ox-carts, wheelbarrows or a tractor with trailer.

First the whole length of the key is filled with a 20 cm thick layer of the clayey soil that is moistened with water and compacted using either tree trunks or cows or a tractor driven back and forth until all air is forced out of the soil. Thereafter, successive 20 cm thick layers of soil are laid out along the whole length of the key and dam wall, and each layer is moistened and compacted, until the top of the dam wall has reached to 30 cm below the surface of the sand in the riverbed.

The upstream and downstream sides of the dam wall, having a slope of about 45 degrees, are then smoothened using shovels and wooden floats. The upstream side of the dam wall should be plastered with clay or cow dung to prevent water from seeping through the dam wall.

Finally, the excavated sand is back-filled against both sides and the top of the dam wall. Two short iron bars should be hammered into the riverbanks at each end of the dam wall, to locate the dam wall in the future (the dam will be invisible after the first flooding).

Subsurface dams being constructed by a self-help community (Kitui, Kenya)

Construction of a subsurface dam

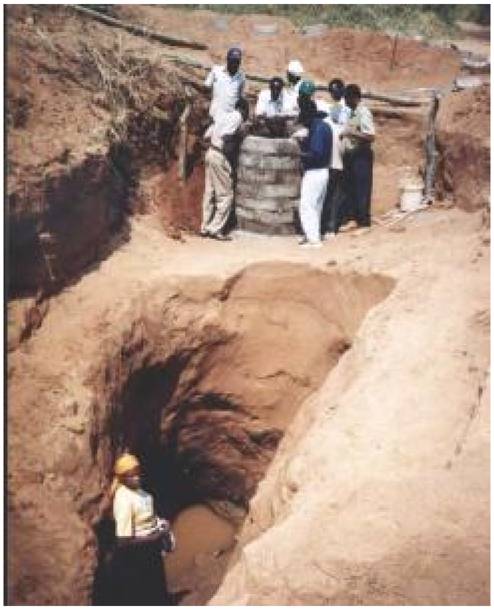
Extraction from shallow ground water sources - Wells, water lifts and pumps

There are several technologies for lifting water from riverbeds that are affordable and sustainable for individuals and community water projects.

Water holes

Waterhole in a riverbed

The oldest and simplest method is to dig a waterhole in a riverbed and use a calabash cut in half to scoop water into a calabash or a jerry can.



Hand-dug well next to a waterhole

A safer and cleaner option is to sink a hand-dug well next to the waterhole in a riverbed. However this option is more expensive.

Hand-dug wells

Hand-dug well

Hand-dug wells situated in riverbeds must be equipped with a well-head to prevent the well shaft being filled with sand during floods such as this hydro-dynamic well-head used in Sudan. It is shaped as a wedge to break the force of floods.

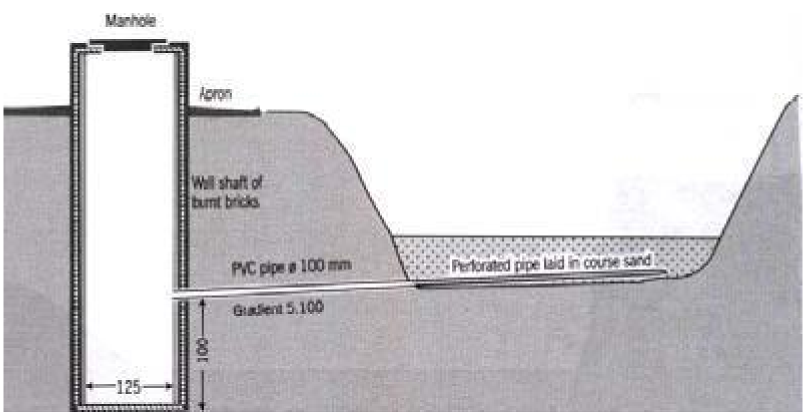
A hydro-dynamic well-head

A well-shaft

A well-shaft can also be lined with worn-out lorry tyres and closed by a lid made from the bottom of an oil-drum as in Somaliland.

Intakes in riverbanks

Although sinking of wells directly into riverbeds is the cheapest way to extract water, the wells might be damaged by unusually large flash-floods. It is therefore safer to build hand-dug wells on the riverbanks and draw water from there provided the underground soil is sandy soil that allows water to seep into the hand-dug wells.



Hand-dug well - underground sketch

If underground water cannot seep into a hand-dug well, an infiltration pipe can be laid in a trench to drain water into the hand-dug well. The design can be made cheaper by filling the trench with stones covered with polythene sheeting instead of laying the infiltration pipe.

Building a hand-dug well

Infiltration pipes can also be installed in a hole drilled buy a jet of water form a length of steel pipe connected to petrol powered pump with a flexible hose pipe. Well shafts can be lined with burnt bricks when built upwards from the bottom of hand-dug wells. However, this procedure is risky because collapsing soil can bury the builders alive.

A safer method is to build a sinking well whereby curved concrete blocks are reinforced together onto a foundation ring made of concrete. The foundation ring is built in the excavation for the well.

Then sand is removed from the inside of the shaft causing it to sink into the sand. When the top of the shaft has sunk to ground level, more blocks are added onto the shaft. Sand is then removed and the shaft sinks. The procedure is repeated until the shaft has reached its final depth. Concrete culverts can be sunk in a similar way but they are more difficult to handle due to their weight.
To ensure inflow of water to a well, U-bend insulated wires can be laid in the lower course of the well shaft. When the shaft has been sunk to its final depth, the wires are pulled and, thereby leaving many small holes through which water can seep into the well. The cost of lining well shafts can be reduced by placing a large perforated PVC pipe in the centre of the excavation and filling stones and gravel all around it up to the ground level.

Small water lifts and pumps for shallow water sources

The simplest and cheapest method to lift water is a bucket tied to a rope.

Extracting water with a bucket

A foot-operated money-maker pump

Water pump

A windlass made of a few Sisal poles

Windlass

Introduction to Shallow Ground Water

Surface water is rainwater running off from land surfaces into rivers, lakes and seas which can be collected, stored and utilized by a technique called *rainwater harvesting.*

To the surface water structures to collect and store water belong ponds and earth dams such as Charco dams, Hillside Dams and Valley dams.

The type of pond, or earth dam, to be constructed for homesteads depends on the type of landscape available for the construction as follows:

1) Charco Dam is suitable for flat land, preferable with a road catchment to supply rainwater run-off.

2) Hillside Dam is the best option for slightly sloping land in places where rainwater flows.

3) Valley Dam can be built in valleys flooded with low floods from small catchments. Although this type of dam is the most cost efficient, it is also the type most easily damaged or washed away by floods if it is not properly designed and constructed.

Charco and Hillside dams are preferably built in circular and oval designs because:

1) They give maximum storage volume for minimum works.

2) The internal and external pressures are evenly distributed and this prevents cave-in of the soil in the walls of the water reservoir.

3) In sandy soils, they can be lined successfully with clayey soil, because the shapes do not have any corners.

Charco dams

Charco dams

Farmers and cattle owners in semi arid parts of Tanzania build small earth dams known as Charco, or Milambo in Kiswahili. These dams are built in a way, which tries to reduce evaporation losses by deepening the water reservoirs and minimising their surface area. Trees and shrubs are grown on the windy site of the charco dams to function as windbreaks and reduce evaporation.

Site selection:

The best sites for constructing charco dams are in natural depressions where rainwater either flows or accumulates during rainy seasons. The soil should, preferably, be deep clay, silt or Black Cotton Soil. Coarse textured sandy soils should be avoided as these are highly permeable and water will drain through them. If seepage is high in charco dams, they can be plastered with clayey soil and compacted using compactors made of tree trunks.

Sites with underlying strata of sand, gravel, limestone or fractured rock at a shallow depth may also result in high seepage losses, unless they are sealed with clayey soil.
Ideally, a charco dam should be located near to a gully or a natural waterway, which carries water during and after rainfalls, as this water can easily be diverted into the dam. Avoid building dams near or downstream from livestock enclosures to avoid organic and/or chemical pollution.

Inflow channel

The photo shows the inflow channel to a charco dam seen in the background. Usually, inflow channels have some logs laid across the floor of the inflow channel functioning as steps and silt traps to prevent the water reservoir from being silted up.

Charco dams are usually excavated manually by individuals near their homesteads for watering livestock. The water may also be used for some domestic purposes, if it is boiled or treated by the Sun's UV rays in transparent bottles (SODIS).

Farmers dig their ponds during dry seasons and enlarge them every year, until the owner is satisfied with the capacity of his dam.

The size of Charco dams depend on the following factors:

1) A farmer's financial capacity to hire labourers to assist him excavating.

2) The expected volume of runoff water from the catchment.

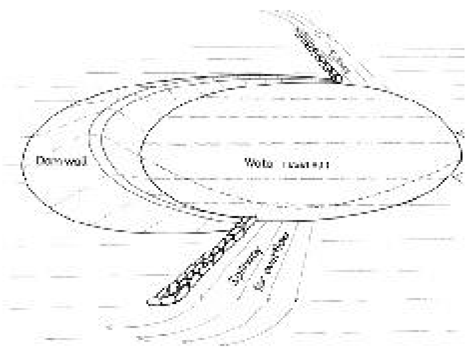
3) The area available for constructing the pond.

4) The soil type

Hillside dams

Hillside dams are small earth dams with curved walls built on hillsides and sloping land are the simplest and second cheapest earth dams to locate, design, construct and maintain.

Site selection: Suitable sites for hillside dams can be found on almost any sloping land that produces rainwater runoff. The catchment can include roads, compounds, roofs, agricultural land and rock outcrops. To avoid contamination of the water, there should not be any pollution sources, such as drainage from villages, slaughterhouses, latrines, rubbish pits, cattle dips, etc. in the catchment area.



A bird's eye view of a hillside dam

Naturally, the best soil type for constructing a water reservoir should have a high content of clay. However, soil types other than the clayey type can also be used, although some seepage may occur downstream.Despite seepage being considered as wasted water, it can be turned into an advantage such as; facilitating clean water in a hand-dug well that can be used for domestic water, watering livestock, garden irrigation, making burnt bricks, a wood lot, etc.
The curved heap of soil, shown above, will become the dam wall, while the excavated pit will be the water reservoir. The size of the dam wall and its reservoir depends on the capacity to remove soil from the reservoir and placing it on the dam wall. The gradient (slope) of the sides of the dam wall should be 2:1, which is 2 m width for every 1m of height.


Curved heap of soil


Hill side dam

Valley dams

An earth dam built in a valley is the cheapest way to create water storage, because the excavation work is less than for Charco dams and hillside dams. However, the gain in cost per volume can be lost overnight by flooding from one heavy thunderstorm or shower, which, unfortunately seem to be bigger and further apart every year. The washout of a dam wall can be very serious and endanger both lives and property. For this reason experienced technical help should always be sought for the design and construction of valley dams which might present a possible threat to downstream households.


Valley dam

Introduction

The quality of water is crucial to ensure the health of the people consuming it. There are three main criteria for water quality: firstly its natural co-compounds like calcium or magnesium, secondly pollution by chemicals like pesticides or fuels, and thirdly biological contamination by bacteria or other microorganisms. Biologically contaminated water can be treated and made palatable. Treatment of chemically polluted water is extremely complex and costly, so the best way is to protect the water sources from chemical pollution.

Quality and Protection of Drinking Water

Chemically pure water is a molecule that consist of two hydrogen atoms bonded to a single oxygen atom. Water is a tasteless, odorless liquid at ambient temperature and pressure, and appears colourless in small quantities, although it has its own intrinsic very light blue hue. Nevertheless, according to experience, water has often a quiet distinct taste. This taste is caused by numerous co-compounds that are solute in the water. The most common compounds of groundwater are calcium and magnesium that are solutes from the rock the water flow through. The concentration of these elements depends on the composition of the respective rock-underground. Calcium and magnesium give the water a special taste and are at the same time essential elements of the human diet. Rainwater lacks of those elements, which has to be considered when consuming only rainwater.

Spring or well water can also contain elements that are toxic when consumed, such as arsene. There are various methods to tread the water.

Chemically polluted water

There are various sources of chemical pollution such as for example spilled fuels, pesticides used on crop fields or in house gardens, or heavy metals leached from rainwater harvesting installations.

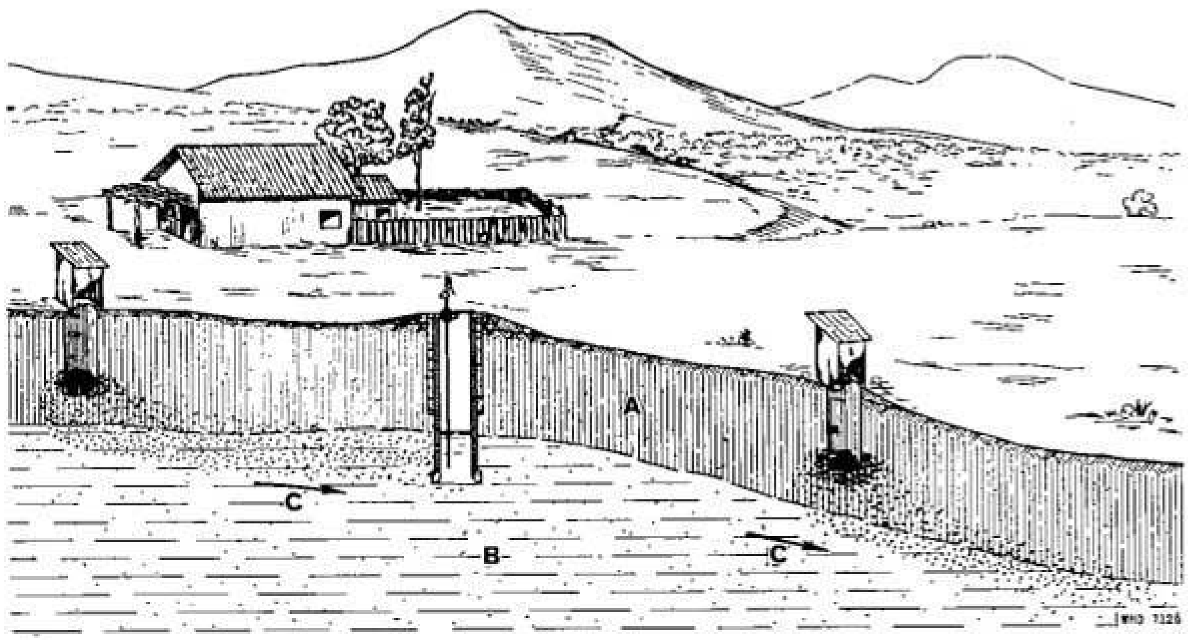
Generally, chemical pollution of water cannot be undone and the water can be rendered unpalatable by chemical pollution. Hence, it is very important to protect water sources from chemical pollution.

Biologically polluted water

Besides chemical pollution by fuels, pesticides, etc., water can also be polluted by microorganisms. Microorganisms can cause , depending on the type and concentration , light to very heavy illness. Diseases such as Amoebiasis, Schistosomiasis, Cholera and many others are waterborne.

Generally, biologically contaminated water can be treated by different methods.

Protecting groundwater from contamination



A = Top soil B = Water-bearing formation C = Direction of ground-water flow

Latrines positioned upstream and downstream of a well (Wagner and Lanoix 1958).

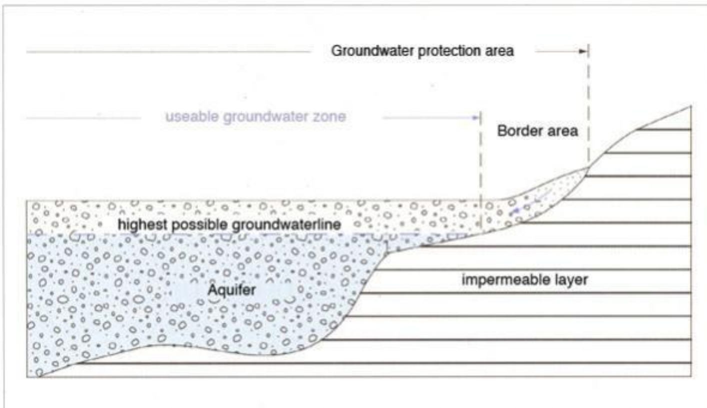
Especially when ground water is near to the surface, i.e. in an unconfined aquifer, it needs to be protected from contamination. There are several causes for pollution of shallow ground water:

1. Drainage of fertilizers and agrochemicals (e.g. herbicides) from fields
2. Seepage of faeces from a latrine pit
3. Seepage from waste deposits
4. Contamination with soluble pollutants from the air
5. Seepage of hazardous pollutants from accidents (e.g. of a petrol truck)

Water infiltrating from the surface, e.g. after a heavy rain, can carry microorganisms from a latrine pit through the soil to the ground water. Thus, when finding a suitable place for a latrine, the ground water flow has to be taken into account. Latrines should always be built downstream to wells or sources. Also other possible sources of contamination should have a minimum distance from wells, sources or surface water. If the watershed of a groundwater flow is known, it should be specially protected, e.g. hazardous transports should not be allowed to pass through the area.

Protecting watersheds

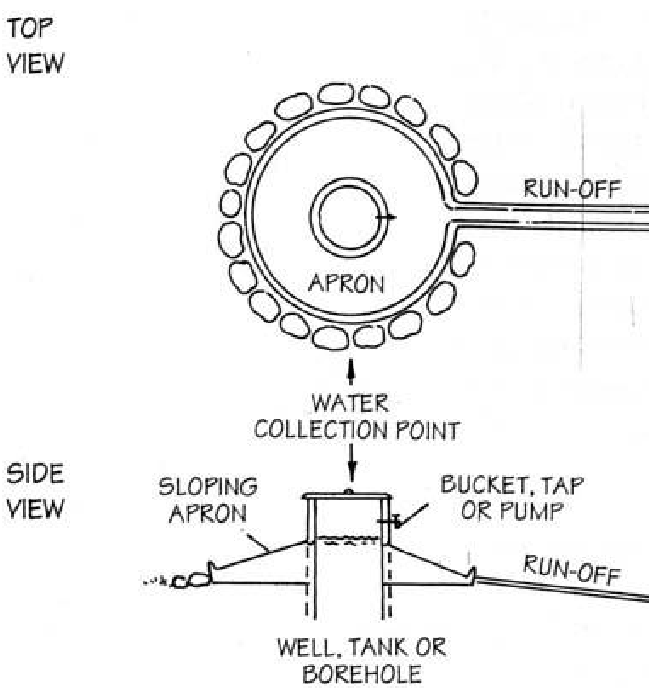
A watershed is defined as any surface area from which all rainwater is drained into the same water catchment. This does not only include surface water streams but also groundwater streams. Ground water is usually built by different layers as shown in the figure below.



Groundwater conservation area (according to BUWAL 2004)

Protecting wells

Wells should be constructed according to certain rules: the well should be protected from run-off or spilled water by a concrete apron with high walls. The concrete for the apron should be of good quality and should not have any cracks that might allow waste water from the surface to return to the source.



Example of a well protected by an apron

Protecting springs

In areas where springs occur, the spring and its surroundings need to be protected from contamination. The area directly around the spring should be fenced to exclude animals and humans. Also the upstream area should be fenced to avoid contamination of the source. The spring chamber should be lined and covered and pipes should be layered to access the water. The access point should be at a safe distance downstream from the spring site.

Preventing loss of water

Water can be lost in different ways: it can run-off, evaporate or being contaminated and not usable any more. How to prevent contamination of the water was discussed above. Evaporation and evapotranspiration (or simply transpiration) gets stronger, the warmer the climate is. Evaporation means the loss of water from the soil surface, transpiration means the loss of water through the leafs of plants. Measures to counter this loss of water include firstly the increase of vegetation, preferably multi storage vegetation, to create shadow and, thus, reducing direct sun; and secondly by reducing the wind speed with hedges and shelter belts. Leaving the soil undisturbed by practicing no, or only a minimal, tillage also reduces evaporation.

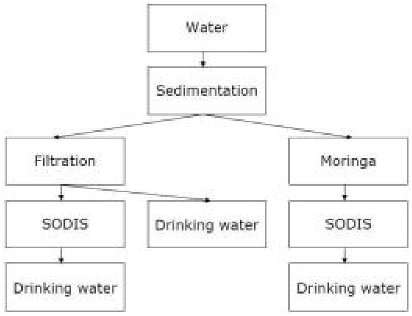
An increased soil cover also increases the infiltration of the water into the soil and, thus, minimizes water run-off. During the rainy season, the surface run-off can be spread by different measures to improve the infiltration of the water. One possible method is to build terraces by constructing barriers. Because of the reduced slope and the spreading of the water, it has more time and a bigger surface area to infiltrate and the terraces at the same time protect the soil from erosion and reduce the damage caused by heavy rain storms.

Barriers can also be built in a way that run-off is diverted to cultivated fields or single trees, providing them with an extra amount of water.

Water Treatment: Filtration, Purification, SODIS

Generally, it can be said that protecting a water source from contamination is easier than treat contaminated water to get safe drinking water.

Contaminated water can be treated with physical or chemical methods. Physical methods include sedimentation, filtration, boiling, and solar water disinfection. Chemical methods include disinfection with chlorine, iodine, silver, or potassium-permanganate. Most of the time, several of those methods are combined to get safe drinking water. The first step is normally to clean the water optically, i.e. remove sediment or filter the solid particles. Then, chemical or biological contamination can be removed by boiling, disinfection or chemical treatment. Alternative purification methods include for example plants like a tree called Moringa which supports the coagulation and subsequent sedimentation of solid particles in turbid water. For many chemical or physical desinfection methods, turbid water is treated less effectively.



Sedimentation

The first step of water treatment is often sedimentation, especially in the cases of turbid water. Generally, the methods used are very simple. The goal is to let the silt sink down and decant the clear water. Since this takes some time, the sedimentation process takes up to two days. Within this time, even pathogen bacteria can be reduced by 97%.

Sedimentation can be done in simple, covered containers. Also simple flow-through sedimentation tanks can be built.
Although the water is normally fairly clear after the sedimentation process, it is not treated enough for drinking. At least one further step, the filtration, is required.

Filtration

Filtration is the next step after sedimentation. It is an easy and cheap way to treat contaminated water. Depending on the types of filter, up to 100% of bacteria and most of the viruses as well as all bigger organisms (cysts, worm eggs, etc.) are being removed.

There are multiple types of filters: sand filters, ceramic filters, and cloth filters.

Slow Sand Filtration

Two types of sand filters can be compared: pressure filters and gravity filters. Pressure filters are often used in industrial water treatment. Here, only gravity filters, which are much cheaper in set-up and maintenance, are considered.

The principle of a sand filter is the following: driven by gravity, water flows through a layer of previously washed sand and gets cleaned from solid particles, dissolved compounds as well as to a certain part microorganisms. In slow sand filtration, a biological layer is formed on top of the sand, which is additionally active in deactivation and removal of pathogens from the water. In rapid sand filtration this additional biological filter is missing and, hence, the water is often chemically pretreated before filtration. Rapid sand filters are suitable for large urban centers where land scarcity is an issue, whereas slow sand filters tend to be more suitable for areas where land is more available, since they need a much larger surface area to treat the same amount of water. Slow sand filtration is simpler to operate than rapid filtration, as frequent backwashing is not required and pumps are not always necessary.

The advantage of slow sand filters is that they can be built locally with local materials. When properly maintained, they remove 90-99% of bacteria and also other pathogens. But they require the proper maintenance such as regular cleaning by scratching away the biological layer on top of the sand. During the first 1-2 weeks of use, the water is not cleaned, because the biological layer has to grow first. Also after cleaning, the filter needs some time to recover.

If the filter has to be cleaned very often, the water is too silty and should be allowed to stand in a large tank or prefiltered beforehand. For prefiltration, an upward flow filter is useful. In an upward flow filter, the bed of coarse (3 to 4mm) sand is supported on a plate pierced all over with 2 mm holes 50 mm apart. The advantage of the upward flow filter is that it is easy to clean the sand bed once a day by shutting the flow off and pulling the drain plug.

Ceramic filters

Ceramic filters have a pore diameter of about 200 nm, which means that it can filter bacteria (usually bigger than 300 nm) and reduce but not totally filter viruses (which can be as small as 20 nm). One simple form of ceramic filters is clay pots. The ceramic filters often have a coating of colloidal silver, which acts as bactericide and enhances the purification effect. Furthermore, the silver hinders bacteria from growing on the ceramic filter surface.

Ceramic filters remove 90-99% of bacteria as well as other pathogens. But compared with slow sand filters, their through flow is much smaller, so they are suitable only for household use. Ceramic filters need regular cleaning and proper handling, so they don't break.

Cloth filters

Cloth filters, mostly made of cotton also filter particles with the size of their pores. Since microorganisms are associated with plankton or other bigger particles, they can also be removed by filters with bigger pore sizes than the size organisms themselves. Cloth filters showed to be effective against cholera or the Guinea worm.

Cloth filters should only be used as a last means if no other way of water purification is available since its effectiveness is lowest compared with the other described filter methods.

Water purification using *Moringa*.

Moringa is a tropical tree with multiple uses, which is resistant to drought. Among the 13 species known, *Moringa oleifera* is particularly easy to reproduce and its growth is very fast. The numerous economic uses of *M. oleifera* together with its easy propagation have raised growing international interest for this tree which originated from India and which is found in most tropical countries (Africa, Asia and America). *M. stenopetala* and other species from Eastern Africa and Madagascar also have potential even though they have been less exploited so far.

All of the parts of *M. oleifera* can be used in a variety of ways. Moringa is full of nutrients and vitamins and is good in human food as well as in animal food. Moringa helps to clean dirty water and is a useful source of medicines. It provides lots of leafy material that can be utilized in alley cropping systems. There are many other uses as for example as fertiliser, living fence, natural pesticide, domestic cleaning agent, and fuel wood. For more information on the different uses of *moringa* click here.

Moringa oleifera has been shown to be most effective as a primary coagulant for water treatment. Thus, seed powder can be used as a quick and simple method for cleaning dirty water. There is a dual advantage to this property:

1. Moringa can be used as a locally-produced substitute for imported flocculent, thus reducing expenditure of foreign currency reserves by third world countries.
2. Moringa flocculent, unlike aluminum sulphate, is completely biodegradable. This aspect may be particularly interesting to developed countries.

The seed powder joins with the solids in the water and sinks to the bottom. This treatment also removes 90-99% of bacteria contained in water. Using Moringa to purify water replaces chemicals such as aluminum sulphate, which are dangerous to people and the environment, and are expensive.

Water from varying sources will need different amounts of powder because the impurities present might not be the same. Experiments with a jar will help in working out the correct amount needed. Honey and sugar cane juice can also be cleared of impurities using the powder. *Moringa stenopetala* seeds have better water purifying properties than *Moringa oleifera*.

Water purification step-by-step

Step 1 Remove the wings and brown seed coat and discard any seed kernels that have dark spots or any other signs of damage.

Step 2 Ground the kernels to a fine powder.

Step 3 Add 2 grams (2 small spoons) of powder to one cup of clean water, pour into a bottle and shake for 5 minutes.

Step 4 Filter the solution through a clean cloth into the bucket of dirty water that is to be treated.

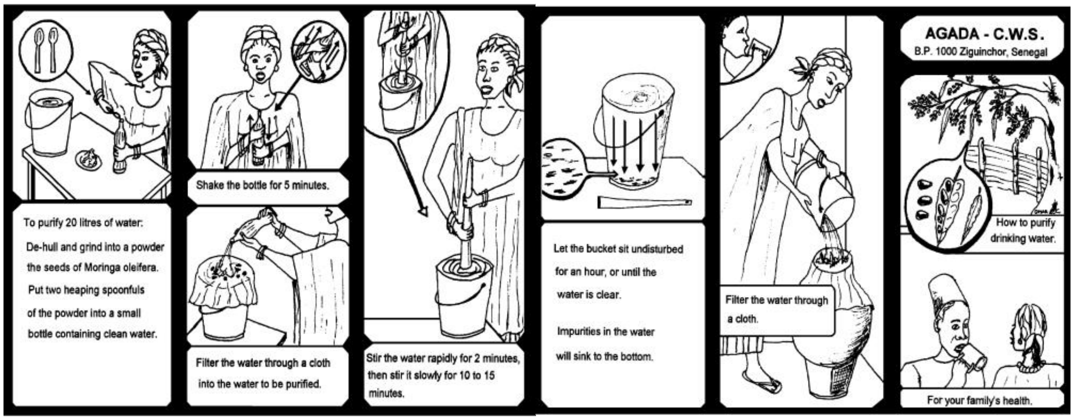
Step 5 Stir the water quickly for 2 minutes and slowly for 10 to 15 minutes (do not use metal implements).

Step 6 Leave the bucket undisturbed for one hour or until the water becomes clear and the impurities have sunk to the bottom.

Step 7 Filter the water through a clean cloth

Step 8 Boil the water before drinking.

Both the seeds and the seed powder can be stored but the solution made in stage 3 should be freshly made every time water is to be purified.



Moringa Water purification 1,2

Functionality

The crushed seed powder, when mixed with water, yields water-soluble proteins that possess a net positive charge and act as a cationic polyelectrolyte that has proved efficient as a substitute to aluminum sulphate and other flocculent. These proteins attach themselves to, and bind between, suspended particles forming larger, agglomerated solids. These flocculated solids then can be led to settle and filtered. Dosing solutions are generally prepared as 1-3% solutions and are filtered prior to application to the untreated water.

Limitations and possible problems

At low turbidity, as may be experienced during the dry season, the seeds are less effective although their performance is very much dependent on the raw water to be treated. For low turbidity, the contact flocculation-filtration process has to be applied.

Despite the usefulness of *M. oleifera* and other similar organic coagulants for treatment of turbid water, there has been little effort to characterize the active agents in these seed extracts or evaluate the efficacy as coagulants in reducing microbes from waters having different turbidities. The findings so far suggest that such seed extracts may function as a particulate, colloidal and soluble polymeric coagulant (see above) as well as a coagulant aid. The presence of other constituents in these seed extracts is uncertain, and there is concern that they may contain toxicants, because the portions of the plant also are used for medicinal purposes.

Boiling

Boiling is the simplest method to remove all pathogens from water. If the water is heavily contaminated, a boiling duration of 3 minutes is recommended. The water should not be poured in another vessel since it could be re-contaminated.
The disadvantages of boiling are the bland taste of the water after cooking and the large amount of energy needed. For one litre of water one kilogram of wood is needed for cooking. In areas with scarce wood availability, it is often hard for the women to collect enough fire wood even for cooking. In forest areas, water treatment by boiling increases the pressure on the forest, which can lead to deforestation and subsequent problems like erosion, water scarceness, and loss of biodiversity.

Solar water disinfection - SODIS

Microorganisms which occur in some water resources used as drinking water can cause water borne diseases such as diarrhoea. SODIS is seen by the World Health Organization (WHO) as one of the technically simplest and most practical and economical ways to improve the quality of such drinking water. Water that is contaminated with microorganisms is filled into clean, transparent plastic bottles and exposed to full sunlight for six hours. The solar radiation and temperature destroy the micro-organisms in the water. This method is ideal to produce small quantities of safe drinking water for the household level. The WHO recognizes that heating water, other liquids and other foods using solar radiation is a more accessible, economical and technologically feasible option than heating with fuel.

Requirements for SODIS

Containers

Plastic bottles made from PET are good containers for SODIS. PET soft drink bottles are often easily available. The containers used for SODIS should not exceed a water depth of 10 cm, i.e. PET bottles of 1-2 litre volume.
To distinguish a PET- from a PVC-bottle, try to inflame it. PVC is difficult to flame. The material does not burn outside the flame. The smell of the smoke is pungent. PET burns easily when held into a flame. The fire goes out slowly or not at all outside the flame. The smell of the smoke is sweet. **You should not use PVC bottles for SODIS**.

Water turbidity and quality

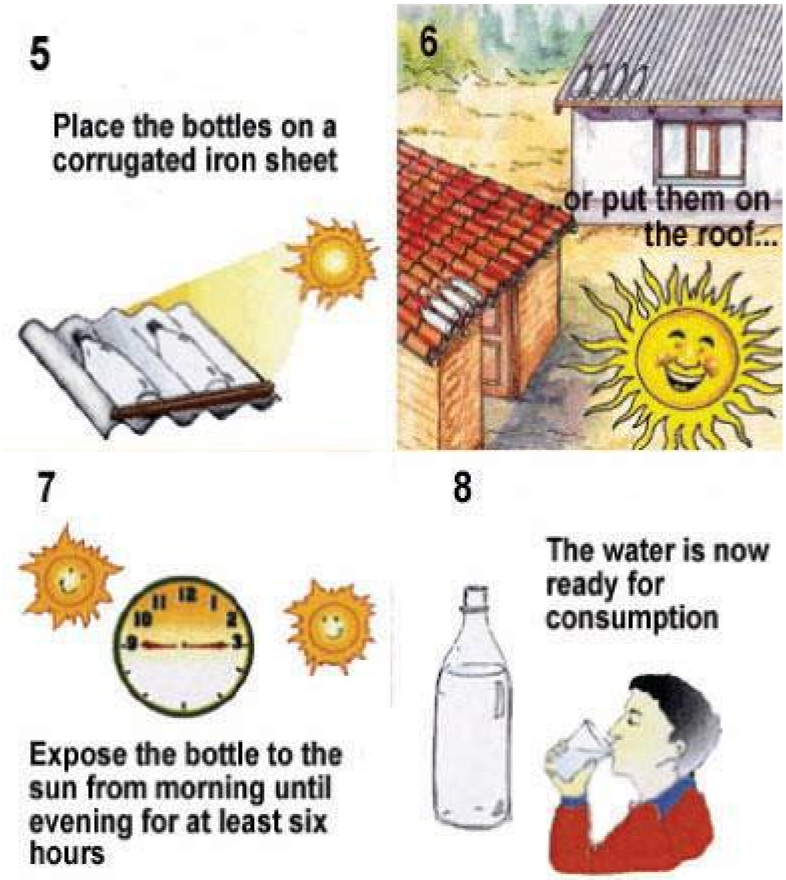
Solar Water Disinfection does not change the chemical water quality. Do not use chemically polluted water. SODIS requires relatively clear water. To test the water turbidity, there is a very simple test: Fill the SODIS bottle with the water and place the bottle on top of a paper with the SODIS-Logo (the letters should have a size of about 1.5 cm). Open the lid of the bottle and watch through the bottle to the bottom of the bottle. If you still can read the letters of the SODIS-Logo on the paper, you can use the water for SODIS. If you cannot read the letters, the water is too turbid for SODIS and needs to be filtered or the solids have to be decanted first. Let the full bottle stand until the suspended particles have sunken to the ground. Filter the water through a clean cotton cloth or filter and fill it into a new bottle without the sunken particles.

Application of SODIS

SODIS exposing procedure, step 1

Step 1: Aerating the water

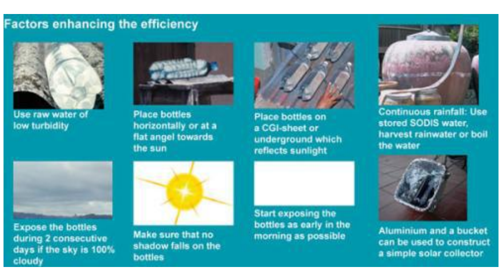
Wash the bottle well the first time you use it. Fill the bottle to 3/4 and close it. Shake it a few times. Then fill it completely with water. This procedure is particularly important if you treat standing water (as for example stored rainwater). Oxygen in combination with sunlight helps destroying the micro-organisms in the water. After shaking, the bottle should be filled completely.



SODIS exposing procedure, step 2

Step 2: Exposure to the sun

The bottle needs to be exposed to the sun for 6 hours if the sky is bright or up to half clouded. If the sky is completely cloudy, then the bottle needs to be exposed to the sun for 2 consecutive days. During days of continuous rainfall, SODIS does not perform satisfactorily. Rainwater harvesting is recommended during these days. After this time, the water is ready for consumption. Place the bottles on a surface: It needs to be fully exposed to the sun, and never shaded during exposure. Protect the bottles from wind cooling - do not place on open wood racks. Place the bottles on surfaces reflecting the sunlight such as corrugated iron sheets, which can enhance SODIS efficiency. Never place the SODIS bottles on inflammable materials, such as cloth or straw. Since the bottles can act as a magnifying lens, they can set fire to inflammable materials.



Factors enhancing SODIS efficiency

Additional: Increasing the efficiency of Solar Water Disinfection

Place the plastic bottles on a corrugated iron sheet, (this will increase the water temperature by about 5degC.)

Use raw water with low turbidity, expose the bottle for two consecutive days on cloudy days, and replace scratched and dull bottles after about one year of regular daily SODIS application.

Factors reducing SODIS efficiency

Common mistakes

Mistake Nr. 1: The containers chosen are too big

- For the best results, plastic bottles of 1-2 litres volumes are used (better surface/volume ratio).

Mistake Nr. 2: Bottles are placed upright

- Laying the bottles horizontally increases the area for sunlight exposure and reduces water depth. Like this, micro-organisms are more easily destroyed.

Mistake Nr. 3: After SODIS treatment, the clean water is filled into contaminated containers and the water is re-contaminated.

- Consume the treated water directly from the bottle using a clean glass or a cup.

Mistake Nr. 4: Green or brown plastic bottles are used for SODIS

- Green or brown bottles do not sufficiently transmit the sunlight. Therefore, use clear transparent bottles only.

Further information on SODIS

How SODIS works

SODIS is used to inactivate the pathogenic microorganisms, predominantly those causing diarrhoea. Most pathogens cannot grow outside the human body apart from a few exceptions such as salmonella, which however requires favourable environmental conditions (e.g. appropriate supply of nutrients).

Sunlight is treating the contaminated water through two synergetic mechanisms: Radiation in the spectrum of UV-A (wavelength 320-400 nm) and increased water temperature. This synergy of UV-A and temperature occurs, if the water temperature rises above 45degC. If the water temperature rises above 50degC, the disinfection process is three times faster. However, through UV-A radiation, SODIS also works in cool climatic areas, such as the Andeas or the Himalaya region, where the water temperature does not exceed 45degC.

Effectiveness of SODIS

The laboratory experiments showed an efficient reduction of the faecal coliforms through SODIS also with initial concentration of 10'000/100 ml up to more than one million/100ml. This is much more than normally encountered in common river and ponds (a few thousand/100 ml or less). However it has to be considered, that the conditions during the experiments are different from practical situations, where the process might not be applied in a strictly controlled way, materials are not optimal and handling of the treated water often is inadequate.

The application of SODIS inactivates the following microorganisms:

Bacteria:	*Escherichia coli, Vibrio cholerae, Streptococcus faecalis, Pseudomonas aerugenosa, Shigella flexneri, Salmonella typhii, Salmonella enteriditis, Salmonella paratyphi*
Viruses:	*bacteriophage f2, rotavirus, encephalomyocarditis virus*
Yeast and mold:	*Aspergillus niger, Aspergillus flavus, Candida, Geotrichum*
Protozoa:	*Giardia spp., Cryptosporidium spp.*

Effect of aerating the water

With the aeration, oxygen is dissolved in the water. SODIS is more efficient in water containing high levels of oxygen: Sunlight produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) in the water. These reactive molecules react with cell structures and kill the pathogens.

Recent research however revealed that the bottles should be shaken only at the beginning of the SODIS process. Once the bottles are exposed to the sun, they should not be moved anymore, as continuous shaking of the bottles during the solar exposure will reduce the efficiency of the process.

The taste of solar disinfected water

When water is boiled, the level of the oxygen dissolved in the water decreases. This changes the taste of boiled water, making it tasteless fresh and softer.
SODIS on the other side improves the quality of drinking water without changing its taste. The bottles are closed during the exposition to the sun. Therefore, the level of oxygen dissolved in the water remains the same. The taste of the water keeps fresh.

Limitations

1. Availability of suitable water containers and other needed materials
2. Lack of sunlight for disinfection
3. Difficulties in treating highly turbid water and the availability of simple methods for reducing the turbidity of water before solar treatment (turbidity less than 30 NTU needed)
4. Lack of a residual disinfectant to protect water during handling and storage. However, stored in the bottle, the treated water is protected from recontamination. No regrowth has been observed so far, even if the treated water was stored for one week.
5. User objections to the technology due to the length of time to treat the water (several hours or longer)
6. Lack of effectiveness against chemical water pollutants
7. Not useful to treat large volumes of water
8. Weaning food for children less than 18 months should be prepared with boiled water.
9. Boiled water instead of SODIS water should be used by persons with a considerably increased risk of infectious diarrhoeal diseases including:

- severely ill children and adults
- severely malnourished children and adults
- patients with decreased immunodeficiency (AIDS)
- patients with gastro-intestinal abnormalities or chronic gastrointestinal illnesses

Possible problems

Repeadedly concerns are expressed abut the possibility of specific compounds leaching from reused and new PET bottles into the water. Therefore, a team of researchers from the EMPA (Swiss Federal Laboratories for Materials Testing and Research) tested the diffusion of adipates and phtalates such as DEHA and DEHP from new and reused PET bottles. The levels of concentration found in the water of reused and new PET-bottles were very low, e.g. in the same magnitude as the concentrations of phtalate and adipate generally found in high quality tap water. Also the concentrations of formaldehyd and acetaldehyd were found to be below the thresholds for safe drinking water . A group of researchers from the University of Heidelberg assessed the diffusion of Antimom from new PET-bottles that had been stored for several months in the supermarket. They found a concentration of 300 to 600 ng antimom per liter. This concentration is far below the WHO threshold value for drinking water (20 ug/l).

Chlorination

Chlorination is still a worldwide used method for the disinfection of water. When used with water filtration methods, chlorine is effective against virtually all microorganisms. Chlorine is easy to apply and small amounts of the chemical remain in the water as it travels in the distribution system or is stored in a tank or cistern. This level of effectiveness ensures that microorganisms cannot re-contaminate the water after treatment.

Chlorination is useful for the treatment of a central water supply in a village but not for individual household use, since its application has to be done in a professional way. The application of chlorine can produce certain by-products that can lead to health problems. Chlorine can also be used as an emergency measure for the disinfection of a water storage that has been accidentally contaminated, e.g. after a storm or by a dead animal.

Introduction

1) Deep ground water can be pumped from deep bore holes but is usually *unsuitable for irrigation* because of minerals in the water as well as high drilling and operational costs.

2) Shallow ground water can be delivered by

- *hand pumps*
- *foot pumps*
- *small petrol pumps*
- From *lakes*, *rivers*, *hand dug wells* and *ground tanks to*

to either elevated tanks from where water is gravitated to the fields, or water can be gravitated directly from the pump onto to the fields. Where the water source is situated at a higher elevation than the field to be irrigated, water can flow by gravity. A siphon pipe can lift water over higher elevated sections.

3) Surface water in streams, rivers and canals can be delivered by gravity in some circumstances. The water can be applied to crops by either:

i *overhead sprinkler*

ii *drip irrigation* by perforated pipes

iii *furrow irrigation* in open ditches

iv *basin irrigation* in flat plots of lands surrounded by soil bounds

v *bucket irrigation* is simply irrigating using a bucket with water.

4) Macro catchments consist of diverting rainwater run-off from external catchments, such as

i *rock outcrops*

ii *hillsides*

iii *roofs* and

iv *roads* by gravity to fields situated at a lower elevation than the catchment areas, by means of :

i *garlands of stones on rocks*

ii *ditches along roads, gutters on roofs*

iii *soil bunds*

iv *cutoff drains* on fields.

Fields can be irrigated with water from macro catchments using:

i *uncontrolled flooding* whereby fields are flooded unevenly all over

ii *furrow irrigation* in open ditches dug between rows of crops

iii *basin irrigation* in flat plots of land surrounded by low earth bunds

iv *drip irrigation* by perforated plastic pipes

Water from macro catchments can also be diverted into *ground tanks* and *earth dams*.

5) Micro catchments are shallow basins where rainwater runs from the upper part into the lower part of the basin where crops and trees are planted. Micro catchments can be:

i *trenches*

ii *half moon basins*

iii *V-shaped basins*

iv *diamond-shaped basins*

v *trapezoidal basins*

vi *contour bund basins with tied ridges*

A common feature of all the shapes is that surplus water in the basins passes safely over their spillways and into the micro catchments situated further downstream in the field.

Smaller means of irrigation are:

i Smaller means of irrigation are called: *Zai pits*

ii *Clay pot irrigation*, whereby water is poured into clay pots buried up to their necks in the ground

iii *Bottle irrigation*, by which bottles filled with water are buried upside down near a plant or tree

6) Spate irrigation is diverting seasonal flood water from valleys, rivers, riverbeds and gullies by gravity onto farm land situated at a lower elevation than the flood water. Some of the flood water in sandy riverbeds sinks into the voids between the sand particles where it replaces air, which escapes to the surface of the floodwater in thousands of bobbles making the floodwater look as if it is boiling.

7) In situ storage is to store rainwater in the voids between soil particles where the rain falls. The technique complements **soil conservation** because the practice conserves and improves the soil structure to the effect that more crops can be grown on less rainfall. The types of structures are called:

i *grass strips*

ii *trash lines*

iii *tied ridges*

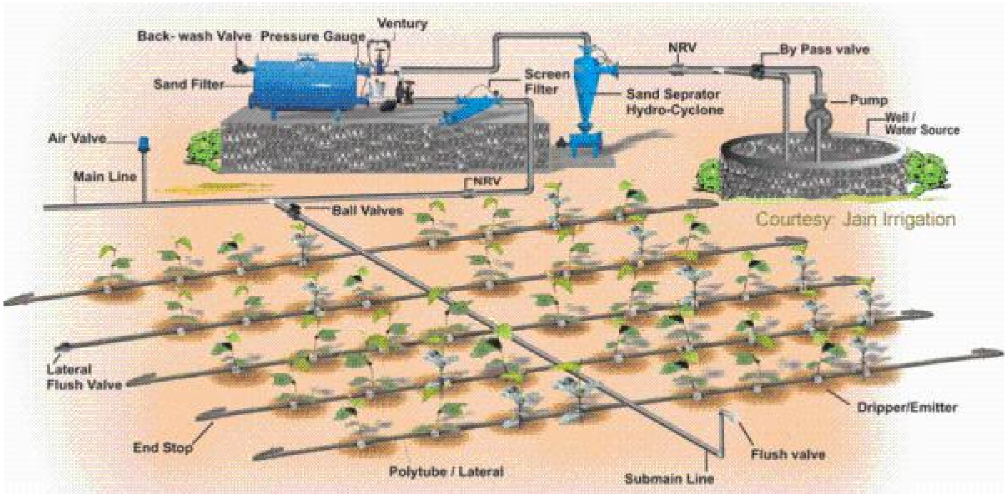
iv *level bunds*

v *graded bunds*

vi *bench terraces*

All structures are laid out on contours (horizontal lines) on the land which is ploughed and cultivated along these contours. Simple techniques of marking contour lines and graded lines as well as measuring vertical intervals and slope gradients are explained.

Drip irrigation



Schematic of a typical commercial drip irrigation system.

In drip irrigation, water flows through a filter into special drip pipes, with emitters located at different spacings. Water is discharged through the emitters directly into the soil near the plants through a special slow-release device. If properly designed, installed, and managed, drip irrigation may help achieve water conservation by reducing evaporation and deep drainage when compared to other types of irrigation such as flood or overhead sprinklers since water can be more precisely applied to the plant roots. In addition, drip can eliminate many diseases that are spread through water contact with the foliage. Finally, in regions where water supplies are severely limited, there may be no actual water savings, but rather simply an increase in production while using the same amount of water as before. In very arid regions or on sandy soils, the trick is to apply the irrigation water as slowly as possible. Irrigation scheduling can be managed precisely to meet crop demands, holding the promise of increased yield and quality.

Expensive drip irrigation systems are employed in highly technical and industrial farming. The used systems are very expensive. Nevertheless, for a relatively low initial investment (US$15 to $85) a small-scale farmer can buy and set up a drip-irrigation system. If used to grow crops for market, this investment will pay itself within the first season and lead to increased household food production, especially during extended dry periods.

Drip irrigation requires little water compared to other irrigation methods. About 40-80 liters per day are needed per 100-200 plants. The small amount of water reduces weed growth and limits the leaching of plant nutrients down in the soil. In organic fertilizer or urine tea can be applied efficiently to the plants through the drip system.

Disadvantages of drip irrigation systems are that most drip-irrigation equipment must be imported, so is not widely available. Furthermore, most experience in using drip irrigation is confined to commercial farmers and research stations. Drip-irrigation systems are subject to clogging, especially if poor-quality water is used. Farmers require training to manage drip irrigation successfully.

Components

1) Pump or pressurized water source

2) Water filter(s) - filtration systems: sand separator, cyclone, screen filter, media filters

3) Fertigation systems (venturi injector) and chemigation equipment (optional)

4) Backwash controller

5) Main line (larger diameter pipe and pipe fittings)

6) Hand-operated, electronic, or hydraulic control valves and safety valves

7) Smaller diameter polytube (often referred to as "laterals" or "tapes")

8) Poly fittings and accessories (to make connections)

9) Emitting devices at plants (ex. emitter or drippers, micro spray heads, inline drippers)

System management

For perennial crops, the drip hose should be lifted periodically if a drip hose system is used on the soil surface, so that leaves, soil, and debris do not cover the hose. If the drip hose is not lifted, roots can grow over the hose, anchor it to the ground, and eventually pinch off the flow of water.

Leaks can occur unexpectedly as a result of damage by insects, animals, or farming tools. Systematically monitor the lines for physical damage. It is important to fix holes as soon as possible to prevent uneven irrigation.

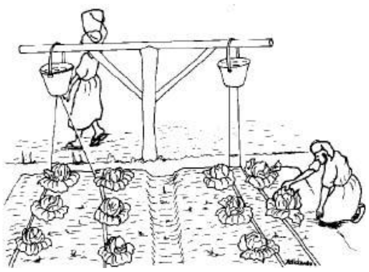
If the rate of water flow progressively declines during the season, the tubes or tape may be slowly plugging, resulting in severe damage to the crop. Once a month, flush the drip lines by opening the far ends of a portion of the tubes at a time and allowing the higher velocity water to flush out the sediment.

Small-scale drip irrigation systems

Bucket system

The bucket system consists of two drip lines, each 15-30 m long, and a 20 liter bucket for holding water. Each of the drip lines is connected to a filter to remove any particles that may clog the drip nozzles. The bucket is supported on a bucket stand, with the bottom of the bucket at least 1 m above the planting surface. One bucket system requires 2-4 buckets of water per day and can irrigate 100-200 plants with a spacing of 30 cm between the rows. For crops such as onions or carrots, the number of plants can be as many as the bed can accommodate. A bucket system currently costs about Ksh 900 (US$ 15). A farmer growing for the market can usually recover this investment within the first crop season.

Drip irrigation system


Bucket drip irrigation system

Drum system

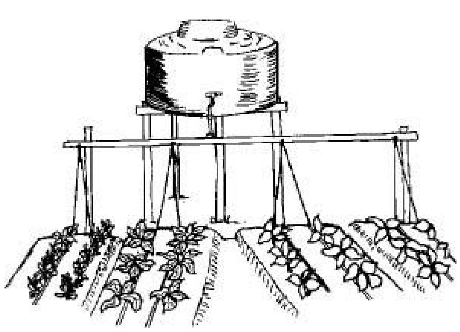
The drum system is a combination of several bucket systems but modified to use a water supply from a 100-200 liter drum instead of a 20 liter bucket. It consists of drip lines measuring 15-30 m long, a lateral line to which the drip lines are connected (including a gate valve) and a drum or a small tank as the water reservoir, raised 1 m above the soil. The equivalent of five to ten bucket kits can be connected in this system. The lateral line is made of 2.5 cm (1-inch) diameter PVC, steel or polyethylene pipes. Connecting tees are used for each pair of drip lines.

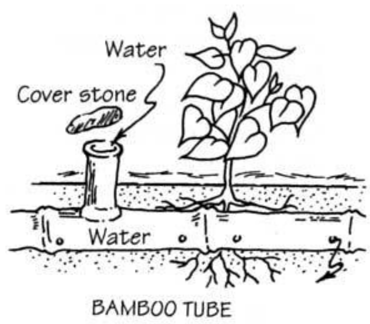
A drum system equivalent to five bucket systems can irrigate 500-1000 plants planted with 30 cm between the rows. Such a system requires about 100-200 liters of water a day, depending on the environment and crop. It costs a total of Ksh 5,000 (US$ 85). For comparison, a crop of cabbage yields a gross return of Ksh 15,000 (US$ 250).

Bucket systems are produced by Chapin Watermatics Inc, 740 Water St, Watertown, NY 13601, USA, and are distributed at low cost. Bucket, drum, one-eighth-acre garden, and orchard kits are currently being promoted and available from the Kenya Agricultural and Livestock Research Organization (KALRO), Nairobi.

Bamboo tube system

Instead of a PVC tube, also a bamboo tube can be used for drip irrigation. The bamboo tube is placed alongside the plants, with small holes in the tube near each plant. Water is put in the open end of the tube, either manually or using a bucket or drum, as described above.


Drum drip irrigation system (IIRR)



Irrigation with a bamboo tube

Pulsed systems

Pulsed irrigation is sometimes used to decrease the amount of water delivered to the plant at any one time, thus reducing runoff or deep percolation. Pulsed systems are typically expensive and require extensive maintenance. Therefore, the latest efforts by emitter manufacturers are focused toward developing new technologies that deliver irrigation water at ultra-low flow rates, i.e. less than 1.0 liter per hour. Slow and even delivery further improves water use efficiency without incurring the expense and complexity of pulsed delivery equipment.

Drip irrigation is adopted extensively in areas of acute water scarcity and especially for crops such as coconuts, in container grown landscape trees, grapes, bananas, brinjal, citrus, strawberries, sugarcane, cotton, maize, and tomatoes.

Drip irrigation systems may be manually operated or may be automatically operated by a controller with valves. Most large drip irrigation systems employ some type of filter to prevent clogging of the small emitter flow path by small waterborne particles. New technologies are now being offered that minimize clogging. Drip and subsurface drip irrigation is used almost exclusively when using recycled municipal waste water. Regulations typically do not permit spraying water through the air that has not been fully treated to potable water standards.

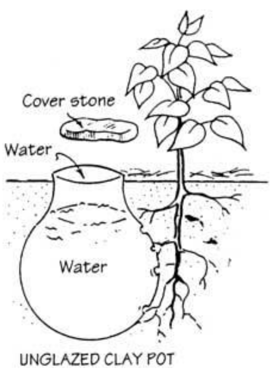
Because of the way the water is applied in a drip system, traditional surface applications of timed-release fertilizer are sometimes ineffective, so drip systems often mix liquid fertilizer with the irrigation water. This is called fertigation.

Fertigation uses chemical injector such as diaphragm pumps, piston pumps, or venturi pumps. The fertilizers may be added constantly whenever the system is irrigating or at intervals. Fertilizer savings of up to 95% are being reported from recent university field tests using drip fertigation and slow water delivery as compared to timed-release and irrigation by micro spray heads.

Others: Pitcher irrigation, Irrigation using a bottle

Pitcher irrigation

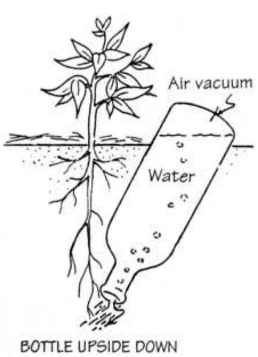
In order to achieve an effective irrigation, unglazed earthenware or clay pots are buried to the neck of the vessel next to plants or small trees. The pots are filled with water and covered with a lid. Since the unglazed walls of the pods are porous, the water can seep slowly out and reach the roots of the plants. Instead of a clay or earthenware pod, also the sweet monkey orange fruit (*Strychnos spinosa* can be used when it has been dried and the top cut off.



Pitcher irrigation using an unglazed clay pot

Irrigation using a bottle

A filled, open bottle can be placed with its neck into the soil next to a plant, so it stands upside down. The dense soil hinders the water from leaving the bottle immediately. Instead, it gets released slowly and directly besides the roots, so it is available to the plant for a longer time and the water cannot evaporate directly.



Small-scale irrigation using a bottle

Introduction

Rains produce plenty of clean water running off roads, roofs, and rocks. This rainwater can be stored for the dry seasons when it is needed most. There are three types of storage, namely:

1) Storage in reservoirs, such as earth dams and ponds.

2) Storage in tanks

3) Storage in situ, such as in soil and sand.

Storage in reservoirs If farmers want to have water during dry seasons, they should 'harvest' it during the annual four months with rain, just like Scandinavian farmers harvest and store sufficient fodder for their livestock during six months of summer to feed their livestock for the 6 winter months when the animals are tied up in stable.

There are many types of structures suitable for surface storage of harvested rainwater but nearly all of them lose water in one way or another, such as:

1) Evaporation. In hot climates it amounts to about 3 mm/day = 90 cm in a month. The solution for water tanks is to roof them but since earth dams cannot be roofed the evaporation losses cannot be reduced.
2) Increased consumption of water from tanks situated next to a house can be caused by neighbours begging for water and children forgetting to close the water tap. This can be avoided by extending the draw-off pipe into the house and locking the water tap.
3) Animals breaking into fenced earth dams are difficult to prevent. A profitable solution could be to charge the livestock owners a fee for watering their animals.
4) Seepage through the floor of earth dams is reduced by silt brought in by rainy seasons but siltation reduces the storage capacity of earth dams.

These, and other, losses of water during storage should be considered when planning designing a water project for either water for domestic user, livestock or irrigation. For example, since about half of the water stored in earth dams will disappear due to evaporation and seepage, the reservoirs should be built to store double the volume of water required.

Storage in Tanks

General guidelines for water storage in tanks

Fresh or purified water can quickly become re-contaminated because:

1) The containers used to store the water are not clean.

2) Unclean things are dipped into the water (this includes hands, clothes, etc.).

3) The water is not covered and so insects, dust or other foreign substances can enter the water.

Chemically disinfected water can have a residual protection which will deal with light recontamination, but even this protection disappears in time. Thus, to prevent recontamination, only clean storage containers should be used and the water should be protected from any contact with objects other than the container. The container requires periodic emptying, washing, and rinsing with scalding or heavily chlorinated water, to prevent the growth of biofilms.

The storage container should be equipped with a practical mechanism to retrieve the water, e.g. a tap (spigot) especially when bigger containers are used.
Storing water for later use is more difficult than collecting water. Ways to store water for household use include tanks or cisterns. Tanks can be constructed of bricks, masonry, corrugated steel sheets, or reinforced concrete, either above ground or below ground. The capacity of the tanks should be determined based on the run-off expected and on the estimated daily use.

Before the rain starts, the tank or storage area should be clean. The first direct flush of rainwater should be directed away from the storage, since it contains the dirt from the catchment area. Cover the tank to prevent evaporation from the sun, keep the water surface clean, and prevent mosquitos from entering the water.

The storage tank should be placed near the place of usage, e.g. the kitchen. Furthermore, there should be a possibility to redirect the overflow or spilled water to a nearby garden or orchard.

Storage tanks and reservoirs can become breeding places for malaria mosquitos. The open water area can be used as breeding places for the mosquitos even in the dry season, when malaria transmission is normally decreased. The open water surface should not be accessible to mosquitoes: the tanks should be covered and all other inlets (taps, ventilation pipes) screened with mosquito-proof mesh. It should also be avoided that breeding sites are established downstream of the overflow.

Storage in Situ

The cheapest method of storing rainwater is to recharge shallow ground water aquifers, also called in situ storage, during rainy seasons and draw the water by means of hand-dug wells throughout the year. However, this cheap method may not always succeed because:

1. The water may seep deep into the underground where it becomes salty and unfit for human consumption

2. The water may be too deep for shallow wells and require investment in expensive boreholes and pumps.

3. The water may not be found in the underground.

Storage of Agricultural Water in Earth Dams

Cut-off drain

Cut-off drains deliver rainwater run-off from roads onto farmland where it sometimes creates erosion and deep gullies. This potentially destructive practice can be changed to a gain for the farmers by diverting the water into ground tanks, small earth dams or land for seasonal irrigation.

Cut-off drain to a pan

Here a cut-off drain diverts run-off water from a road into a natural and shallow depression on the lower side of a road called a **pan**. A pan can be made into a **pond** by deepening the reservoir and place the excavated soil as a dam wall (embankment) with two spillways (overflows) on the lower side of the reservoir. Ponds are small **earth dams**

A borrow pit

Where road contractors have excavated murram for road construction and left 'borrow pits' or 'murram pits', these can be converted into pans or ponds by digging a trench to divert water from a road into the pit. Usually these pits have water-tight (impermeable) floors through which water cannot leak into the underground.

Charco dams

Charco ponds and **Charco dams** are half-ball shaped (hemi-spherical) excavations where the soil is placed as a dam wall around the excavation, except at the inflow channel which has two spillways for safe discharge of surplus water. Charco ponds and dams are viable in flat land.

Hillside dam

Hillside ponds/dams have a semi-circular dam wall made of the soil excavated for the water reservoir. A stony spillway is built onto each end of the dam wall. These dams are designed to be constructed on rolling land and hill sides

Valley dam

Valley dams are straight dam walls built across narrow points in valleys. A wide spillway lined with stones is built at each end of the dam wall to discharge surplus water safely. Due to global warming, many valley dams have been damaged by extraordinarily big thunder storms exceeding the design criteria of the highest rainfall in the last 50 years.

Excavation dams

Excavation dams should be circular or oval excavations where the excavated soil is used for building the dam walls whose sides should slope at least 45 degrees. The excavation dam in the above photo was a waste of money and labour. The sides are too steep and therefore collapsing. The soil is too porous and can therefore not hold any water.

Excavation ponds

The photo above shows a series of well designed and constructed excavation ponds have been filled with run-off water from roads. The embankments should be stabilised with grass.

Storage of Agricultural Water in Ground Tanks

There are two main types of water tanks, namely:

1) Ground tanks that are built below the ground level. These are mainly used for storage of dirty run-off water from roads and compounds. Ground tanks can also be used as storage for clean domestic water if the tanks are roofed and connected to gutters attached to roofs or rocks.
2) Surface tanks standing on the ground level which are cylindrical and mainly used for storage of run-off water from roofs and rocks.

Cylindrical ground tank

Ground tanks should always be designed as either hemi-spherical (half ball shape) or cylindrical because those shapes equalize the pressure of water and soil whether the tanks are full or empty.

This hemi-spherical tank (see image above) built of burnt bricks reinforced with barbed wire and chicken mesh is for roof catchment of domestic water.

Never design square and rectangular tanks.
They will collapse!

This photo shows a rectangular tank for fish farming in Myanmar. Two sides of the tank caved in when the tank was emptied of water due to pressure from the soil.**Note:** Water tanks should never be designed using square and rectangular shapes because they will collapse due to the uneven pressure of water and soil whether the tanks are full or empty.

Traditional underground cylindrical water tank in Botswana

A traditional underground cylindrical water tank at a homestead in Botswana from which water is drawn by a bucket tied to a rope. The catchment area for the tank is the threshing floor for millet and sorghum, which is made water repellant with a coat of cow dung. The floor slopes towards a silt trap where a plastic bottle prevents mice and lizards entering the tank.

A cylindrical ground tank made of ferro-cement

A series of two hemi-spherical ground tanks built of burned bricks collect and store run-off water from a school compound for irrigation of a tree nursery and small irrigation garden.A roof catchment tank can be seen at the school building. It provides drinking water for the pupils.

Berkad ground tanks in Somaliland

The berkad ground tanks for watering livestock in Somaliland are banned by the government because of environmental degradation due to over-grazing caused by insufficient fodder. Moreover, most of the rectangular berkads must be repaired every year due pressure from the soil when the tanks are empty.

Berkad ground tank in Kenya

In Kenya, the rectangular berkad was redesigned to be oval-shaped and roofed with barbed wire covered with thorny Bougainvillea climbers, two large silt traps and a staircase made of concrete for drawing water by hand in buckets.

Catchment area in the Kalahari Desert in Botswana

The hard sandy surface of the Kalahari Desert in Botswana is used as catchment area for these three large cylindrical water tanks, which provide domestic water for the San people (Bushmen).

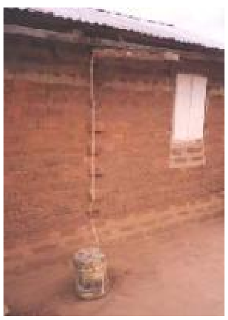
Building a cylindrical water tank in Tanzania

In the dry central plateau of Tanzania, a 500 m^3 cylindrical water tank, made of reinforced concrete, was built to collect run-off water from a 2 sq.km catchment area. The water is for domestic use by the communities living nearby.

This ground catchment tank is known as "King David's Well" in the Negev Desert of Israel and it is estimated to be about 2,500 years old. The conical ground tank is lined with lime stones mortared together with lime mortar. The catchment area is a large stony hill from where the annual rainfall of 100 mm falling in the month of December is diverted into the tank by long trenches sloping upwards from the tank.

Storage of Domestic Water in Tanks

Water from road catchments should not be used for domestic consumption because the water from murram and dirt roads contains dung and other pollutants, while water from tarmac roads contains tar which is harmful to peoples' health.
Water for domestic use should be collected from either roofs, rocks or drawn from shallow ground water by means of hand-dug wells or hand-drilled boreholes.



Simple roof catchment

Roof catchments for domestic water can be as cheap and simple as the photo on the left shows. A sheet of metal or of polythene or a length of split Bamboo or Sisal pole is tied to the roof. A rope hangs from the gutter to facilitate rainwater running along the rope into a 20 litres jerry can on the ground.

Plastic jerry cans

Woman carrying water

Plastic jerrycans play a very important role in rural water supply because nearly all domestic water is transported from the water sources to the homesteads in jerrycans. Many women in dry areas have to carry one full jerry can of 20 litres of water, which is equal to 20 kg, on their back every second day. In addition the women must also walk up to 10 km with the empty jerry can from the homestead to the water source which is usually in a riverbed. They must also wait at the riverbed until it is their turn to fill their jerry cans with the water that seeps slowly into the waterholes they have scooped out of the sand.

They must walk 10 km up hill with the 20 kg jerry can because riverbeds are always in valleys. At home they must ration the 20 litres of water to be sufficient for 2 days consumption because no woman has the stamina to fetch water from 10 km away every day, while also taking care of her children, livestock and homestead.

Transporting water home by donkey

Where water has to be fetched from sources further away than 10 km a donkey has to be purchased. A donkey can carry 4 jerry cans of water for distances up to 30 km during a return trip taking 2 days.

In those dry areas the cost of a donkey is equal to the dowry for a wife. When the rain comes, the cost of a donkey decreases because water can be fetched nearby, while the cost of dowry increases because now manual labour is needed in the fields.

Transporting water with a bicycle

Nowadays, some people prefer bicycles to donkeys for fetching water because bicycles are cheaper and more versatile than donkeys, although a bicycle can only carry a maximum of 3 jerry cans which is 60 kg of water.

Repairing a jerry-can

Jerry cans are expensive for rural communities, therefore jerry cans have to be repaired when they leak or get worn out.

Should a jerry can be worn out, the leakages and holes in it can be sealed by plastic strips melted over a fire.

Oil drums

Most rural homesteads can afford an oil drum to harvest rainwater from the roof. Unfortunately, the lower part of oil drums corrodes. The oil drums are than discarded as scrap metal.

Note: Rusty and leaking oil drums can easily be repaired for the cost of half a bag of cement. The technique is simple.

Repaired oil drums

How to repair oil drums:

Step 1: Mix a 1/8 of a bag of cement with coarse river sand in a ratio of 1 part of cement to 3 parts of river sand.
Step 2: Smear the mixture onto the inside of the oil drum in a 1cm layer and let it dry for a day.

Step 3: Next day apply a second coat of mortar 1:3 being 2 cm thick onto the interior of the drum and smoothen it.
Step 4: Within the same day, mix cement with water until it becomes a slurry called NIL and press it onto the interior plaster with a square steel trowel.
Step 5: Keep the oil drum under shade and sprinkle the plaster with water 3 times a day for a week, then fill it up with water.

Many people plaster their new oil-drums this way because the taste of the water drawn from drums coated with cement mortar has a nice sweet taste.

A simple roof catchment system with gutters

The image left shows a slightly larger roof catchment system with gutters fixed sloping along the full side of the roof. A discharged oil-drum with a storage capacity of 210 litres is placed under the lowest point of the gutters where the rainwater will fall from the gutter.

An oil drum used for roof catchment at a rural home

Types of Water Tanks

Water tanks made of PVC for storage of rainwater can be bought from manufacturers but the cost of the tanks and the transport required to bring them to rural areas is high, although some manufacturers can give up to 50% discount.

It is often cheaper to use locally available materials and experienced builders to construct water **tanks of concrete** in situ (formwork), burnt bricks, soil compressed blocks, quarry blocks and concrete blocks reinforced with a spiral of barbed wire. Water tanks can also be built of **ferro-cement** made of cement, coarse and clean river sand, chicken mesh, weld mesh and galvanized wires.

For any type and size of water tank these must always be circular, hemi-spherical or spherical (ball shaped) in order to distribute the internal pressure of water equally on the tank walls.

Square or rectangular tanks will always crack

Storage tanks should always be roofed with airtight covers to prevent mice, rats, lizards and snakes from entering, drowning and contaminating the water. Airtight covers will also reduce evaporation losses in hot climates. Several types of roofs can be fitted onto tanks, although domes build of ferro-cement are the most durable.

The construction cost of the various types of materials and sizes of water tanks varies according to the availability of local materials and skills as well as the cost of transportation. A budget should be prepared to compare the cost of constructing tanks with the cost of purchasing prefabricated water tanks.

Preferably, water should be extracted from storage tanks by gravity through a draw-off pipe of galvanized iron which is concreted into the foundation of tanks.

Although water can be drawn from tanks situated under the ground level, hereafter called **ground tanks**, by a bucket tied to a rope, or other types of simple water lifts and hand pumps, it is safer and easier to draw the water from a staircase leading down to a water tap and pipe which is concreted into the bottom of the ground tank.

Easy ways of building water tanks

Farmers and laymen have built several thousands of 5,000 litres water tanks using a technique called ***in situ*** which consists of compacting concrete reinforced with a spiral of barbed wire in between two cylindrical moulds made of either roofing sheets or old oil drums.

Local artisans, who can build houses, can usually also build water tanks of burnt bricks, soil compressed blocks, quarry blocks or concrete blocks. The volume of such tanks may vary in sizes from 3,000 litres to 30,000 litres.

It is important that the reinforcement of these tanks is made by wrapping a barbed wire, g 12.5, tightly around the outer side of the tank in a spiral spaced 5 cm at the lower half of the tank, where the greatest strength is needed, and 10 cm on the upper half.

How to Repair Water Tanks

Often it is much easier and cheaper to repair old and leaking water tanks and containers than buying or building new ones.

1) Corrugated galvanized iron sheet tanks

A leaking **water tank** made of galvanized iron sheets

Water tanks made of galvanized iron sheets were popular some decades ago. Unfortunately, the bottom part of the tanks corroded and leaked after 5 to 10 years. They were then considered useless and discharged as scrap metal. These corroded and leaking water tanks can be repaired easily.

Chicken mesh tied to the interior of a tank

The technique is as follows:

Step 1 Small holes are punched in the wall for every 15 cm or so using a nail and a hammer.

Step 2 Binding wire is cut in lengths of about 20 cm and bent in a U shape. One person puts the two ends of a U bent wire into two punched holes situated near each other.

Step 3 A second person presses chicken mesh against the wall and uses the two ends of the U wire to tie to chicken mesh tightly against the wall. Thereafter chicken mesh is laid on the floor of tank.

Step 4 Cement can now be mixed with clean river sand in a ratio of 1 part cement to 3 parts sand and some water. This mortar is then thrown onto the chicken mesh in a layer of about 1 cm thick.

Step 5 The next day another coat of mortar is added until all binding wires and chicken mesh are covered with mortar. Within the same day, cement slurry (NIL) is pressed onto the moist plaster with a square steel trowel for water proofing. The outside of the tank can be painted with a weatherproof paint made of 1 part cement to 10 parts of lime mixed with water.


A repaired tank

2) Leakage between wall and foundation

Problem: Many tanks built of masonry leak water through the joint where the wall joins the foundation.

Reason: The reasons are either insufficient reinforcement, poor mixture of mortar or lack of cleanliness when the joint was made.

Remedy: The joint can be made watertight by cleaning the joint, adding more reinforcement and making an apron on both sides of the joint.

Procedure:

Step 1 Drain all water out of the tank and clean the floor and the foundation on the outer side of the tank.

Step 2 Chisel a groove, about 3 cm x 3 cm, all around the joint on both the interior and external sides of the tank.

Step 3 Roughen a 15 cm wide stretch of the foundation on both sides of the joint. Clean the joint and the roughened surface with plenty of water.

Step 3 Wrap 5 rounds of barbed wire tightly around the tank in the external groove.

Step 4 Compact mortar 1:3 into the external and internal grooves with a piece of timber.

Step 5 Compact a 15 cm wide and 10 cm high apron over the external and internal grooves.

An internal apron can be made with a short length of bamboo or an empty beer bottle.

An external apron is made with a wooden trowel.

3) Leakage through a cracked foundation

Problem: Water leaks through cracks in the foundation.

Reason: Soft soil under the foundation, insufficient reinforcement, poor mixture of concrete or improper curing.

Remedy: The leakage can be sealed by constructing a new foundation onto the old cracked foundation.

Procedure:

Step 1 Drain all water out of the tank and clean the floor.

Step 2 Fill all cracks with bitumen paste

Step 3 Cut sheets of weld mesh to fit the foundation. All overlaps must be at least 20 cm and tied together with binding wire for every 10 cm.

Step 4 Mix concrete with 1 part cement to 3 parts river sand and 3 parts of crushed stones (1:3:3). Compact a 7 cm thick layer of concrete onto the old foundation.

Step 5 Lay the weld mesh on the concrete in the tank.

Step 6 Compact a second layer of 7 cm concrete onto the weld mesh in the tank.

Step 7 Compact a 1 cm thick layer of mortar 1:3 onto the concrete. Smoothen the plaster and press a coat of NIL onto the plaster the same day.

Step 8 The next day, compact a rounded apron into the joint between the new foundation and the wall.

Step 9 Keep the foundation moist and under shade for 3 weeks

Weld mesh cut to fit foundation.

4) Leakage through walls without cracks

Problem: Water leaks through the wall of a water tank, although the wall has no cracks.

Reason: The wall is leaking due to porosity caused by either a mortar mixture with insufficient cement, insufficient curing or poor workmanship.

Remedy: The wall can be sealed by replacing the porous parts with mortar 1:3 and with NIL. Should the wall still leak after that treatment, the interior of the tank should be coated with a water proofer.

Procedure:

Step 1 Drain all water out of the tank and clean its interior

Step 2 Chisel away the porous parts of the interior wall.

Step 3 Clean the chiseled parts with water and throw dry cement onto the watered parts of the wall.

Step 4 Mix mortar of 1:3 and throw a thin layer of it onto the watered parts of the wall.

Step 5 Step 5 Next day, fill up the coated parts with mortar 1:3 and apply NIL with a square steel trowel. Keep the plastered parts moist under shade for 3 weeks, and then fill the tank with water.

Step 6 Should the tank still leak, its internal side has to be painted with a water proofer, such as swimming pool paint, non-toxic bitumen, oil paint or 1 part of cement with 10 parts of lime mixed with water.

A newly plastered tank must be cured for three weeks.

5) Leakage through cracked walls

Problem: Water leaks through cracks and fissures in the wall of a water tank.

Reason: Vertical cracks are due to insufficient horizontal reinforcement and/or incorrect joining of bricks and blocks. Horizontal cracks are due to incorrect joining between the horizontal courses between bricks and blocks.

Remedy: Build a new tank on the outside of the cracked tank by wrapping reinforcement mesh or wire around the tank and plaster it.

Procedure:

Step 1 Drain all water out of the tank and clean it.

Step 2 Chisel off any loose part on the external side of the tank wall

Step 3 Tie sheets of weld mesh together with binding wire and wrap them tightly around the tank and plaster the outside of the tank with 3 cm of plaster 1:3. Alternatively, wrap chicken mesh tightly around the cracked tank after which a spiral of barbed wire, gauge 12.5 is wrapped tightly around the chicken mesh with a spacing of 5 cm at the lower half of the tank and 10 cm apart on the upper part of the tank. Thereafter plaster the outside of the tank with 3 cm of plaster 1:3.and keep it moist under shade for 3 weeks.Paint the tank with a weather proof paint made of 1 part cement to 10 parts of lime mixed with water.

Weld mesh wrapped around a tank.

Chicken mesh and barbed wire wrapped around a cracked tank.

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