RAINWATER HARVESTING

Small dam harvesting water for animals and smallholder irrigation, Kenya. (Hanspeter Liniger)

In a nutshell

Definition: Rainwater Harvesting (RWH) refers to all technologies where rainwater is collected to make it available for agricultural production or domestic purposes. RWH aims to minimise effects of seasonal variations in water availability due to droughts and dry periods and to enhance the reliability of agricultural production. A RWH system usually consists of three components: (1) a catchment / collection area which produces runoff because the surface is impermeable or infiltration is low; (2) a conveyance system through which the runoff is directed e.g. by bunds, ditches, channels (though not always necessary); (3) a storage system (target area) where water is accumulated or held for use - in the soil, in pits, ponds, tanks or dams. When water is stored in the soil - and used for plant production there - RWH often needs additional measures to increase infiltration in this zone, and to reduce evaporation loss, for example by mulching. Furthermore soil fertility needs to be improved by composting / manuring, or micro-dosing with inorganic fertilizers. Commonly used RWH techniques can be divided into micro-catchments collecting water within the field and macro-catchments collecting water from a larger catchment further away.

Applicability: RWH is applicable in semi-arid areas with common seasonal droughts. It is mainly used for supplementary watering of cereals, vegetables, fodder crops and trees but also to provide water for domestic and stock use, and sometimes for fish ponds. RWH can be applied on highly degraded soils.

Resilience to climate variability: RWH reduces risks of production failure due to water shortage associated with rainfall variability in semi-arid regions, and helps cope with more extreme events, it enhances aquifer recharge, and it enables crop growth (including trees) in areas where rainfall is normally not sufficient or unreliable.

Main benefits: RWH is beneficial due to increased water availability, reduced risk of production failure, enhanced crop and livestock productivity, improved water use efficiency, access to water (for drinking and irrigation), reduced off-site damage including flooding, reduced erosion, and improved surface and groundwater recharge. Improved rainwater management contributes to food security and health through households having access to sufficient, safe supplies of water for domestic use.

Adoption and upscaling: The RWH techniques recommended must be profitable for land users and local communities, and techniques must be simple, inexpensive and easily manageable. Incentives for the construction of macro-catchments, small dams and roof catchments might be needed, since they often require high investment costs. The greater the maintenance needs, the less successfully the land users and / or the local community will adopt the technique.

Development issues addressed	
Preventing / reversing land degradation	++
Maintaining and improving food security	++
Reducing rural poverty	+
Creating rural employment	+
Supporting gender equity / marginalised groups	+
Improving crop production	+++
Improving fodder production	++
Improving wood / fibre production	++
Improving non wood forest production	na
Preserving biodiversity	+
Improving soil resources (OM, nutrients)	+
Improving of water resources	+++
Improving water productivity	+++
Natural disaster prevention / mitigation	+
Climate change mitigation / adaptation	+++

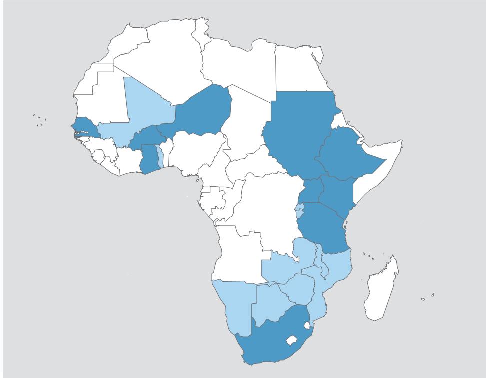
Climate change mitigation	
Potential for C Sequestration (tonnes/ha/year)	0.26-0.46 (+/-0.35)*
C Sequestration: above ground	+
C Sequestration: below ground	+

Climate change adaptation	
Resilience to extreme dry conditions	+++
Resilience to variable rainfall	+++
Resilience to extreme rain and wind storms	+
Resilience to rising temperatures and evaporation rates	++
Reducing risk of production failure	+

for a duration of the first 10-20 years of changed land use management (Pretty et al., 2006)

Origin and spread

Origin: A wide variety of traditional and innovative systems exists in the Sahelian zone e.g. Burkina Faso, Egypt, Kenya, Niger, Somalia, Sudan. In some cases these traditional technologies have been updated and (re-)introduced through projects or through the initiative of land users.
Mainly applied in: Burkina Faso, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Sudan, Tanzania, Uganda
Also applied in: Botswana, Burundi, Malawi, Mali, Mozambique, Namibia, Rwanda, Togo, Zambia, Zimbabwe



Spread of Rainwater Harvesting in SSA.

Principles and types

In-situ rainwater conservation (sometimes not classified as RWH) is the practice where rainfall water is captured and stored where it falls. Runoff is not allowed and evaporation loss is minimised. This is achieved through agronomic measures such as mulching, cover crops, contour tillage, etc. Those technologies are further described under conservation agriculture.
Micro-catchments (for farming) are normally within-field systems consisting of small structures such as holes, pits, basins, bunds constructed for the collection of surface runoff from within the vicinity of the cropped area. The systems are characterised by relatively small catchment areas ‘C’ (<1,000 m^2) and cropping areas ‘CA’ (<100 m^2) with C:CA = 1:1 to 10:1. The farmer usually has control over both the catchment and the storage area. The water holding structures are associated with specific agronomic measures for annual crops or tree establishment, especially fertility management using compost, manure and / or mineral fertilizers. Common technologies are *zaï* / tassa (planting pits), *demi-lunes* (half-moons), semi-circular / trapezoidal bunds, etc.
Micro-catchments such as *zaï / tassa* are often combined with conservation agriculture. This may be referred to as ‘**African-Adapted Conservation Agriculture**’. Its focus is on water harvesting and applying fertilizers rather than maintaining soil cover. Traditionally, CA is poorly suited to areas where water is a limiting factor and provision of permanent soil cover is a problem due to the competition between materials for mulch and livestock fodder. African style CA encompasses the following aspects: minimal soil disturbance (e.g. using jab planter), water harvesting, fertilizer application and hand weeding or low-cost herbicide.
Macro-catchments (for farming) are designed to provide more water for crop or pasture land through the diversion of storm floods from gullies and ephemeral streams or roads directly onto the agricultural field. Huge volumes of water can be controlled through large earth canals often built over many years. The systems are characterised by a larger catchment outside the arable land with a ratio of C:CA = 10:1 to 1000:1. Common technologies are: check-dams, water diversion channels / ditches, etc.
In the cultivated area through different practices and by manipulating the soil surface structure and vegetation cover, evaporation from the soil surface and surface runoff can be potentially reduced, infiltration is enhanced and thereby the availability of water in the root zone increased.
Small dams / ponds are structural intervention measures for the collection and storage of runoff from different external land surfaces including hillsides, roads, rocky areas and open rangelands. Sometimes runoff is collected in furrows / channels below terraces banks. Small dams / ponds act as reservoirs of surface and floodwater to be used for different purposes e.g. for irrigation, livestock and / or domestic use during dry periods.
Roof catchments: Rainwater harvesting from roofs is a popular method to secure water supplies for domestic use. Tiled roofs, or roofs covered with corrugated iron sheets are preferable, since they are the easiest to use and provide the cleanest water. Thatched or palm leafed surfaces are also feasible, but are difficult to clean and often taint the runoff. Water is collected and stored in plastic, metal or cement tanks. Roof catchments provide water at home, are affordable, easy to practice, can be shared by several houses or used on public infrastructure (schools, clinics, etc.).

Top: *Demi-lune* micro-catchments in an arid zone, Niger. (Hanspeter Liniger)
Middle: Collection and storing water in a small pond, Rwanda. (Malesu Maimbo)
Bottom: Roof catchment for domestic water use, Kenya. (Hanspeter Liniger)

Applicability

Land degradation addressed

Water degradation: aridification through decrease of average soil moisture content and change in the quantity of surface water
Erosion by water: loss of fertile topsoil through capturing sediment from catchment and conserving within cropped area
Physical soil deterioration: compaction, sealing and crusting
Chemical soil deterioration and biological degradation: fertility decline and reduced organic matter content

Land use

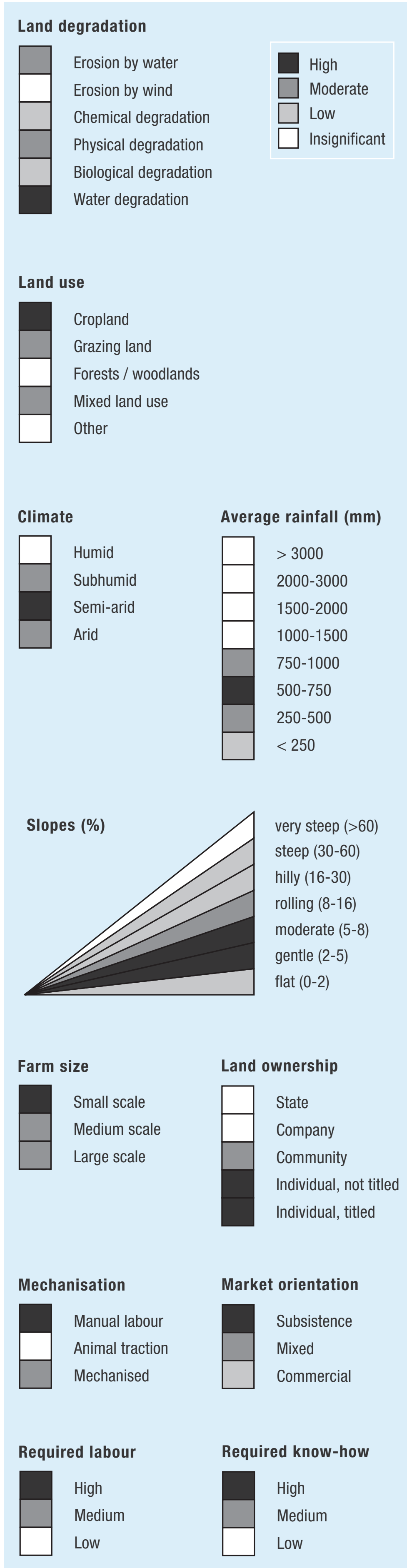
Mainly used on annual cropland with cereals (sorghum, millet, maize), leguminous grains / pulses (cowpeas, pigeon peas etc.) vegetables (tomatoes, onion, potatoes, etc.) and tree crops; also used on mixed extensive grazing land with trees. Micro-catchments are mainly used for single trees, fodder shrubs, or annual crops, whereas macro-catchments and concentrated runoff harvesting are mainly used for annual crops, but have also been used on mixed extensive grazing land with tree crops.

Ecological conditions

Climate: RWH techniques are most relevant in semi-arid and subhumid zones with poorly distributed rains, in particular in cereal–based areas. In more arid regions they are used for tree crops and / or establishing trees for afforestation. Micro-catchments are more suitable for areas with more reliable rainfall, whereas macro-catchments are effective in areas where few runoff events are expected.
Terrain and landscapes: Macro-catchments can be applied in depressions / valleys, whereas micro-catchments can be used on all landforms.
Soils: Clay or shallow soils with low infiltration rates in the collection area and deep soils with high moisture storage capacity in the storage areas. This makes them suitable for deep flooding for subsequent cropping on residual moisture - though waterlogging can be a problem. Sandy soils have quicker infiltration but lower storage capacity: they are thus relatively suitable for diversion schemes.

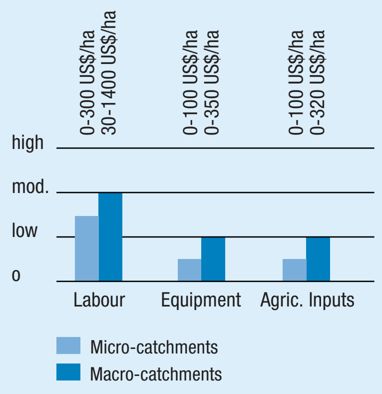
Socio-economic conditions

Farming system and level of mechanisation: Micro-catchments are mainly small-scale and constructed manually or by animal traction. Macro-catchments for runoff harvesting and small dams / ponds may be applied within medium or large-scale systems, and the construction is usually mechanised - but may be built up manually over many years.
Market orientation: Both subsistence and partly commercial.
Land ownership and land use / water rights: The absence of clear land and water use rights prevents water harvesting and conveyance techniques from being more widely spread.
Skill / knowledge requirements: For the establishment of rainwater harvesting techniques, medium to high level of know-how is required.
Labour requirements: Roof catchments, macro-catchments and small dams require high initial labour input, whereas micro-catchments usually need mainly medium labour input depending on the technique used. Micro-and macro-catchments and small dams also require a certain level of labour for maintenance. Many techniques can be implemented manually.

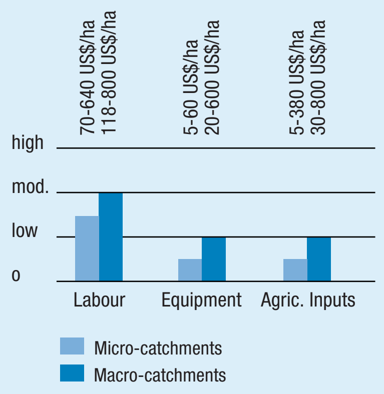


Economics

Establishment costs



Maintenance costs



Labour is valued as 1-2 US$ per person day (Source: WOCAT, 2009)

Micro-catchments: Main costs are for labour (establishment and maintenance); inputs are mainly agricultural such as compost, fertilizer, etc., equipment is less important than for macro-catchments. Labour days can vary considerably and range between 80 - 250 person days/ha.
Macro-catchments: Main costs are for labour. Maintenance costs depend heavily on the quality of the structures; they are usually low for well-built structures. In case of breakages maintenance costs can be very high (compared to micro-catchments).
Small dams: Costs for a size of 50-80,000 m³ approximately 120,000-300,000 US$ (this translates to about 1.5-6 US$ per m³ of earth dam material)
Ponds: Costs about 4 US$ per 1 m³ excavation
Roof catchments: Storage tanks cost about 200 US$ per m³ of water (a tank is typically 10 m³ ➜ 2,000 US$) (the same if plastic tanks are used or ferrocement tanks (except that the cement tanks are logistically much more demanding and require much greater skills). Both of them last more than 10 years.

Production benefits

Crop	Yield without SLM (t/ha)	Yield with SLM (t/ha)	Yield gain (%)
Burkina Faso Millet	0.15 – 0.3	*Zaï* + manure 0.4 (poor rainfall) 0.7 - 1 (high rainfall)	30-400%

(Source: FAO, 2001)

Comment: For roof catchments and for small dams, ponds, etc. no directly related production benefits can be shown. The main benefits are related to the availability of clean and free household, as well as irrigation water.

Benefit-Cost ratio

System	short term	long term	quantitative
Micro-catchments	+/++	++	
Small dams, etc.	– –	++/+++	
Macro-catchments	– –	++/+++	Returns to labour, 10-200 US$/PD vegetables 10 US$/PD* for maize
Roof catchments	– –	+++	
Overall	–	++/+++	

– – negative; – slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive
**PD: person days. (Sources: WOCAT, 2009 and Hatibu, et al., 2004)*

Comment: Due to the required level of maintenance activities the costs for micro-catchments are slightly less positive in the long term than for roof catchments and small dams / ponds, etc.

Example: Niger
Cost of selected RWH techniques

Erosion control / SLM techniques	Indicative costs US$/ha
Stone lines *Cordon de pierres*	31
Stone lines with direct seeding *Cordon de pierres avec semis direct*	44
Earth bunds *Banquette en terre*	137
Earth bunds manual *Banquette en terre manuelle*	176
Half-moon for crops *Demi-lune agricole*	111
Half-moon for trees *Demi-lune forestière*	307
Planting pits *Zaï*	65

(Sources: Projet d'Aménagement Agro-Sylvo-Pastoral Nord Tillabéry (PASP); Projet Développement Rural Tahoua (PDRT))

Example: Tanzania
In Tanzania a study was conducted on the productivity of RWH techniques. The results showed that farmers using RWH for maize and paddy could increase crop yields. However the yield achieved can be depressed through higher labour requirements as well as low market prices. Other factors in production, such as fertility management, are essential for higher crop yields. Micro-catchments led to higher benefits than the use of storage ponds and macro-catchments, even though the increase in crop yield was higher with the latter, but the return to labour for storage ponds and macro-catchments is lower than for micro-catchments. The study also showed that using RWH techniques like storage ponds and macro-catchments is very beneficial for the production of vegetables with returns to labour of between 10 US$ and 200 US$ per person day, whereas for maize and paddies it rarely exceeds 10 US$ per person day. One reason for the better return under vegetables is the higher market price (Hatibu, et al., 2004).

Crops	Return to labour* (US$/person days)
Maize	4.6
Paddy	5.2
Tomatoes	13
Onions	87

**for RWH techniques using external runoff and storage ponds (mean return from 1998 to 2002)*

Impacts

Benefits	Land users / community level	Watershed / landscape level	National / global level
Production	+ + increased crop yields (a, b, c)* ++ enhanced water availability ++ increased fodder production (a, b, c) + increased wood production (a, b, c) + diversification of production	++ reduces risk of crop failure (a, b, c) +++ access to clean and free drinking water (d) +++ reduced damage to neighbouring fields	+++ improved food and water security
Economic	+++ access to clean / free drinking water (d) ++ increased farm income	++ less damage to off-site infrastructure + stimulation of economic growth + diversification and rural employment creation	+++ improved livelihood and well-being
Ecological	+++ improved water availability ++ can be used for rehabilitation of highly degraded land (a, b) ++ improved water infiltration (a) ++ reduced velocity of runoff (a) ++ reduced net surface runoff (a and b) ++ increased net soil moisture (a) ++ reduced soil erosion and soil loss (a) ++ improved excess water drainage (a) + increases soil organic matter and soil fertility (a) + improved soil cover (a) + biodiversity enhancement + sediment traps for nutrient (a, b)	++ reduced degradation and sedimentation (a) ++ increased stream flow in dry season / reliable and stable low flows (a, b, c) + groundwater recharge + reduced groundwater / river pollution (a, b) + intact ecosystem	+++ increased resilience to climate change ++ reduced degradation and desertification incidence and intensity + enhanced biodiversity
Socio-cultural	+++ less pressure on water resources for drinking water, irrigation, etc. ++ community institution strengthening ++ improved conservation / erosion knowledge (a, b, c) ++ can reduce the time used for gathering water for domestic use	+ increases awareness for environmental 'health' ++ reduced water conflicts ++ national institution strengthening + attractive landscape	+ protecting national heritage

**a) Micro-catchments, b) Macro-catchments, c) Small dams / ponds, d) Roof catchments*

	Constraints	How to overcome
Production	• Very often RWH alone does not always lead to a significant production increase, additional fertility management is needed (a, b, c)	➜ combine with improved soil fertility management
Economic	• Increased input constraints especially for the establishment • Availability of manure to improve soil fertility especially within micro-catchments • Establishment and construction can be labour intensive and requires a high level of technical knowledge • Maintenance of the system and limited life-span of certain types of structures – for micro-catchments this mainly refers to annual agronomic activities, whereas for small dams and macro-catchments maintenance includes also reparation and protection against animals as well as siltation • Loss of land (decreased production area) especially for very small farms (a, b, c) • Lack of market (a, b, c) • Cost of transportation of the material (a, b, c)	➜ access to market for inputs and equipment and if necessary support for establishment ➜ technical support in form of training and education on the system is needed ➜ for small-dams, ponds, etc. community organisation is needed for the establishment and the maintenance with clear responsibilities ➜ most successful techniques are simple, inexpensive, easily manageable by local community (includes stone bunds, semi-circular bunds, vegetative strips)
Ecological	• Waterlogging can be a problem under poor drainage systems (a, b, c,) • Water can only be harvested when it rains	
Socio-cultural	• Conflicts in areas formerly used by nomads • Where RWH is used over a significant area, there may be upstream / downstream conflicts in terms of water availability • Socio-cultural conflicts concerning rehabilitated land • Eliminates women's burden of collecting water for domestic use (d)	➜ clear land and water use rights and improved watershed planning with allocation of water resources ➜ farmer and community involvement

Adoption and upscaling

Adoption rate

In general adoption rates remain low. Farmers hesitate to invest time and money in RWH without security of land and limited access to local markets where they can sell surpluses. However some RWH technologies like *zaï* have been widely adopted with (and in some areas, without) external support.

Upscaling

Profitability: The techniques recommended must be profitable for land users and local communities, and techniques must be simple, inexpensive and easily manageable.

Capacity building and knowledge sharing on suitable RWH techniques is needed. One of the constraints hindering adoption is lack of information, education and training

The level of maintenance is an important criterion. The techniques should be manageable at farm level and involve community action, especially for larger-scale construction such as ponds, small dams and macro-catchments which are very often out of the land user's control.

Clear land and water tenure and property rights are necessary to motivate land users to invest in RWH.

Market access: A better linkage and access to markets is necessary, and assistance for small-scale farmers to change from subsistence to commercial farming.

Micro-catchments usually need a low level of material and technical support . However, depending on the techniques, a certain level of material and / or technical support is needed, e.g. *demi-lune* / half moon techniques in West Africa require a relatively high level of material support for the establishment. In Burkina Faso the *zaï* system has been successfully spread through farmer-to-farmer visits. Farmer-to-farmer exchange can be a highly successful tool for upscaling of micro-catchment systems.

Macro-catchments and small dams are very often not within reach of small communities and usually require material and technical support for the establishment as well as community involvement / organisation in the planning and maintenance of the system.

Roof catchments: Relative high investment costs might require initial material support for the construction. Community involvement is needed for the establishment and maintenance. Trained extension services and self-help groups and organisations are very effective and needed for spreading of the technology.

Incentives for adoption

(1) For micro-catchments a low level of material and technical support is needed; (2) macro-catchments and small dams require high material and technical support for establishment; and (3) roof catchments need high levels of material and technical support for establishment.

Enabling environment: key factors for adoption	
Inputs, material, incentives, credits	++
Training and education	++
Land tenure, secure land use rights	+++
Access to markets	++
Research	++
Infrastructure	++
Genuine ownership on the part of communities	+++

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TASSA PLANTING PITS - NIGER

Tassa planting pits are used for the rehabilitation of degraded, crusted land. This technology is mainly applied in semi-arid areas on sandy / loamy plains, often covered with a hard pan, and with slopes below 5%.
Planting pits are holes of 20-30 cm diameter and 20-25 cm depth, spaced about 1 m apart in each direction. They are dug by hand. The excavated earth is formed into a small ridge downslope of the pit for maximum back capture of rainfall and runoff. Manure is added to each pit, though its availability is sometimes a problem. The improved infiltration and increased nutrient availability brings degraded land into cultivation.
Common crops produced in this water harvesting system are millet and sorghum. At the start of the rainy season, seeds are sown directly into the pits. Silt and sand are removed annually. Normally the highest plant production is during the second year after manure application. The technology does not require external inputs or heavy machinery and is therefore favourable to spontaneous adoption.
Tassa are often combined with stone lines along the contour to enhance water infiltration, reduce soil erosion and siltation of the pits. Grass growing between the stones helps increase infiltration further and accelerates the accumulation of fertile sediment.

SLM measure	Structural
SLM group	Rainwater Harvesting
Land use type	Silvopastoral / wasteland (before), cropland (after)
Degradation addressed	Loss of topsoil (by water and wind); Soil compaction / crusting; Soil fertility decline; Soil moisture problem
Stage of intervention	Rehabilitation
Tolerance to climate change	Increased tolerance due to water harvesting

Establishment activities

1. Digging pits (*tassa*) with a hoe in the dry season (20-25 cm deep, 20-40 cm in diameter): the excavated earth forms ridges downslope of the hole. The pits are spaced 0.8-1 m apart, giving approximately 10,000 pits/ha.
2. Manuring the pits with approx. 250 g per pit (2.5 t/ha).
3. Optionally: Digging out stones from nearby sites (using a pick-axe and shovel) and aligning the stones along the contour with the help of a 'water tube level': maximum of 3 stones wide. The distance between the stone lines is a function of the slope: at a 2% slope (or less) the lines are spaced 50 m apart, at a 5% slope, spacing is 25m.

All activities are carried out by manual labour.

Maintenance / recurrent activities

1. Removing sand from the *tassa* (annually, March-May).
2. Manuring the pits with about 250 g per pit (2.5 t/ha) every second year in October / November or March-May.

All activities are carried out by manual labour.

Labour requirements

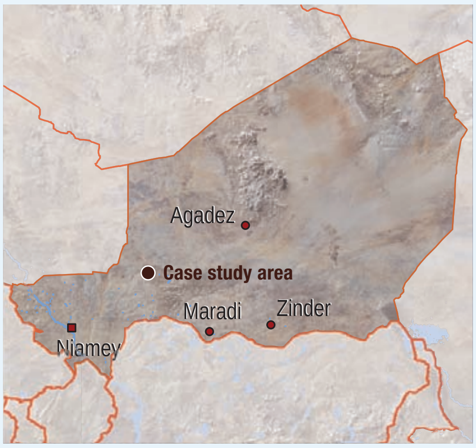
For establishment: high
For maintenance: low

Knowledge requirements

For advisors: moderate
For land users: low

Photo 1: Adding manure to the pits (*tassa*) before planting. (William Critchley)
Photo 2: Digging pits and piling up a small bund on the downstream side, using a traditional hoe. (William Critchley)
Photo 3: Sorghum growing in planting pits. (Philippe Benguerel)

Case study area: Tahoua, Niger



Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour: 100 person-days	150
Equipment	5
Agricultural inputs	5
TOTAL	**160**
% of costs borne by land users	100%

Remarks: Establishment costs are for 2 pits.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 20 person-days	30
Equipment	0
Agricultural inputs	2.5
TOTAL	**32.5**
% of costs borne by land users	100%

Remarks: Labour costs are indicated for establishment of *tassa* only (without application of stone lines). Maintenance costs refer to removing sand from the pits from the second year onwards, and to manuring every second year (costs are spread on an annual basis). If applicable, costs for transporting the manure need to be added. The general assumption in these calculations is that adequate manure is readily available close by. Land users bear 100% of all costs.

Benefit-cost ratio

Inputs	short term	long term
Establishment	neutral	slightly positive
Maintenance	slightly positive	positive

Remarks: Initial labour inputs pay out on the medium to long term.

Ecological conditions

- Climate: semi-arid
- Average annual rainfall: 250-500 mm
- Soil parameters: well drained, sandy, shallow soils; low to very low soil fertility; low organic matter (<1%); soil crusting
- Slope: mostly gentle (2-5%), partly flat (0-2%)
- Landform: mainly plains / plateaus, partly footslopes
- Altitude: 100-500 m a.s.l.

Socio-economic conditions

- Size of land per household: 2-5 ha
- Type of land user: small-scale farmers
- Population density: no data
- Land ownership: mostly individual, titled
- Land use rights: individual
- Market orientation: mostly subsistence, partly mixed (subsistence and commercial)
- Level of mechanisation: manual labour

Production / economic benefits

+++ Increased crop yield
++ Increased farm income

Ecological benefits

+++ Improved soil cover (long term)
++ Increased soil moisture
++ Increased soil fertility
++ Increased soil organic matter
++ Reduced soil loss

Socio-cultural benefits

++ Improved conservation / erosion knowledge
+ Community institution strengthening through mutual aid in technology implementation

Off-site benefits

++ Reduced downstream flooding
+ Reduced downstream siltation

Weaknesses ➜ and how to overcome

- Implementation constraint: availability / transport of manure and transporting manure to the plateaus and slopes ➜ subsidise transport means (or supply donkey carts).
- High labour input for implementation and maintenance ➜ mechanisation of tasks: transportation of manure. However, this would raise the cost.
- Instability of planting pits in loose soil, increased erosion on steeper slopes and with heavy rains ➜ avoid sandy soils and steep slopes; combine with additional measures (e.g. stone lines).
- The effectiveness can be compromised if the various geo-morphological units (plateaus, slopes) are not treated simultaneously ➜ catchment area approach if downstream flooding is an issue.
- Possibility of land use conflicts concerning rehabilitated land, in particular with pastoralists (because grazing land is being turned into cultivated fields) ➜ better coordination / consultation before implementing the technology in an area.

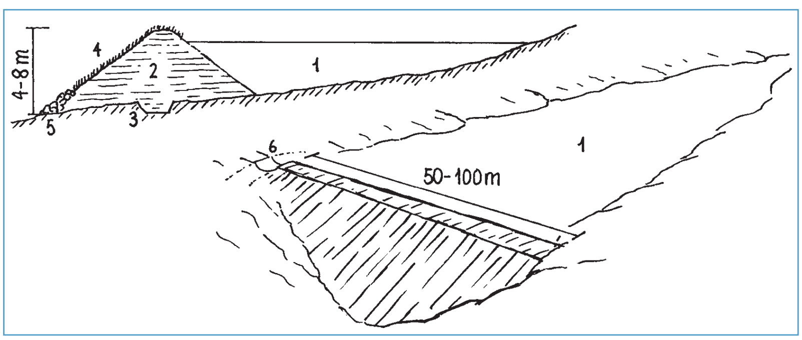
Adoption

There is a moderate trend towards spontaneous adoption (for rehabilitation of the plains). Area covered by the technology was approx. 40 km² in 2000.

Main contributors: Adamou Oudou Noufou, Tahoua, Niger
Key references: Bety A, A. Boubacar, W. Frölich, A. Garba, M. Kriegl, A. Mabrouk, Noufou O, Thienel M and Wincker H (1997): Gestion durable des ressources naturelles. Leçons tirées du savoir des paysans de l'Adar. Ministère de l'agriculture et de l'élevage, Niamey, 142 pp. ■ Hassane A, Martin P and Reij C (2000) Water harvesting, land rehabilitation and household food security in Niger: IFAD's Soil and Water Conservation Project in Illela District. IFAD, Rome, 51 pp. ■ WOCAT 2009, WOCAT Database on SLM Technologies, www.wocat.net

SMALL EARTH DAMS - ZAMBIA

Small earth dams are water harvesting storage structures, constructed across narrow sections of valleys, to impound runoff generated from upstream catchment areas. Construction of the dam wall begins with excavation of a core trench along the length of the dam wall which is filled with clay and compacted to form a central core ('key') that anchors the wall and prevents or minimises seepage. The upstream and downstream embankments are built using soil with a 20-30% clay content. During construction – either by human labour, animal draught or machine (bulldozer, compacter, grader etc.) – it is critical to ensure good compaction for stability of the wall. It is common to plant Kikuyu grass (*Pennesetum clandestinum*) to prevent erosion of the embankment. The dam is fenced with barbed wire to prevent livestock from eroding the wall.
Typical length of the embankment is 50-100 m with water depth ranging 4-8 m. An emergency spillway (vegetated or a concrete shute) is provided on either, or both sides, of the wall for safe disposal of excess water above the full supply level. The dam water has a maximum throwback of 500 m, with a capacity ranging from 50,000 – 100,000 m^3. The dams are mainly used for domestic consumption, irrigation or for watering livestock.
If the dams are located on communal lands, their establishment requires full consultation and involvement of the local community. The government provides technical and financial assistance for design, construction and management of these infrastructures. Community contribution includes land, labour and local resources. The community carries out periodic maintenance of the infrastructure – including vegetation management on embankment, desilting etc. – and of the catchment areas (through soil and water conservation practices).



SLM measure	Structural
SLM group	Rainwater Harvesting
Land use type	Cropland; Grazing land
Degradation addressed	Water degradation: reduced surface water availability
Stage of intervention	Mainly prevention and mitigation, partly rehabilitation
Tolerance to climate change	Sensitive to climatic extremes (e.g. floods); Tolerant with respect to rainfall variability, prolonged dry spells, etc.

Establishment activities

1. Site selection in consultation with community.
2. Dam survey and design: Topographical survey of dam area; using levelling equipment (dumpy level or theodolite); Determination of dam wall dimensions.
3. Dam wall construction: Excavate core trench (usually 4 m wide; 2 m deep). Excavate and transport clay-rich soil to the dam site. Construct core and embankments (slope angles 3:1). Continuously compact placed soil.
4. Construct lateral spillway(s), 5-30 m wide (depending on the flood flow and the return slope).
5. Design and installation of irrigation and drainage infrastructure (in case of crop production).
6. Completion: plant Kikuyu grass on dam embankment, spillway and irrigation canals and fence of; alternatively line with cement.

Maintenance / recurrent activities

1. Catchment conservation to minimise siltation of dam and irrigation infrastructure (continuous).
2. (Re-)planting grass on dam and irrigation infrastructure (annually, using hand hoes).
3. Desiltation of the dam (every 5-10 years): excavate and remove the silt deposited in the dam.
4. Cleaning of dam and irrigation infrastructure: remove trees / shrubs from dam / canals. If concrete lined: repair of any damages.

Establishment and maintenance of structures is carried out by human or animal labour or by machine (i.e. bulldozers or tractors with scoop).

Labour requirements

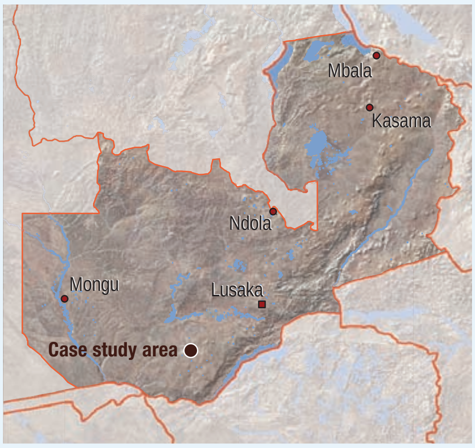
For establishment: high
For maintenance: low to medium

Knowledge requirements

For advisors: high
For land users: high

Photo 1: Manual construction of a small dam requires community action: soil is transported in bags, piled up and compacted layer by layer.
Photo 2: Fetching water for domestic use at a small dam.
Photo 3: Water point for livestock. (All photos by Maimbo Malesu)
Technical drawing: Dimensions and main components of a small dam: (1) water body; (2) dam wall (with layers of compacted soil; side slopes 3:1); (3) central core ('key'); (4) grass cover; (5) stone apron; (6) spillway (Mats Gurtner).

Case study area: Southern Province, Zambia



Establishment inputs and costs per dam

Inputs	Costs (US$)
Labour: 633 person-days	2,000
Equipment / tools: machinery, ox-ripper, hoe / pick, shovel (US$ 3/m³ of earth work)	30,000
Agricultural inputs: termicide, grass seed, fertilizer	3,000
Construction material: cement, sand, stones, abstraction pipes, screen, valve, bolts and nuts	15,000
TOTAL	**50,000**
% of costs borne by land users	20%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 63 person-days	200
Equipment / tools: hoe, axe, shovel	2,000
Agricultural inputs: grass seed, fertilizer	300
Construction material: cement, stones, building sand	1,500
TOTAL	**4,000**
% of costs borne by land users	80%

Remarks: Establishment costs are calculated for a dam with an earthwork volume of 10'000 m^3 (44 m long; 8 m deep; side slopes 3:1). 20% of costs are borne by the community (in-kind contribution: labour and local materials such as sand, stones). Construction machinery can include: tipper truck, bulldozer, motor scraper, compactor, tractor, grader.

Benefit-cost ratio

Inputs	short term	long term
Establishment	negative	very positive
Maintenance	neutral	very positive

Ecological conditions

- Climate: semi-arid, subhumid
- Average annual rainfall: 700 mm (400-800 mm)
- Soil parameters: medium fertility; medium depth, well drained, medium organic matter content; loamy to sandy soil texture
- Slope: plains (2-15%) and valleys (15-40%)
- Landform: plains and valleys
- Altitude: 300-1,200 m a.s.l for mid Zambezi valley and Southern plateau respectively

Socio-economic conditions

- Size of land per household: 2 ha
- Type of land user: small-scale; land user groups; poor
- Population density: 10 persons/km²
- Land ownership: communal (not titled)
- Land use rights: communal (organised)
- Level of mechanisation: animal traction
- Market orientation: mixed (subsistence and commercial)

Production / economic benefits

+++ Increased crop yield
+++ Increased irrigation water availability
++ Increased animal production
++ Increased farm income

Ecological benefits

+++ Increased water quantity
+++ Improved water harvesting / collection
++ Recharge of groundwater table / aquifer
+ Reduced hazard towards adverse events

Socio-cultural benefits

+++ Improved food security
++ Community institutional strengthening
+ Increased recreational opportunities

Off-site benefits

+++ Increased water availability
+++ Reduced downstream flooding

Weaknesses ➜ and how to overcome

- Dams are communally owned ➜ requires strong organisation and commitment by community.
- Risk of siltation ➜ de-silting and catchment conservation is essential
- Vulnerability to climate change ➜ increase depth and design storage to last at least for two rainy seasons.
- Evaporation and seepage losses ➜ maintain minimum design depth of 4 meters; if seepage is high: provide impervious material on the upstream embankment, i.e. clay or plastic lining if necessary.

Adoption

Records of 1991 indicate at least 537 such dams exist in Zambia. In the study area there are over 293 dams serving a cattle population of 1.1 million and human population of nearly 1 million people. Communities require government or NGO support for establishment.

Main contributors: Maimbo Malesu, ICRAF-CGIAR; Nairobi, Kenya; m.malesu@cgiar.org
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RUNOFF AND FLOODWATER FARMING - ETHIOPIA

Runoff and floodwater farming is a traditionally practiced water harvesting system which helps overcome problems of soil moisture and crop failure in a hot, dry area with erratic rainfall and shallow, highly erodible soils: floodwater and runoff from ephemeral rivers, roads and hillsides is captured through temporary stone and earth embankments. A system of hand dug canals – consisting of a main diversion canal and secondary / tertiary canals – conveys and distributes the captured water to the cultivated fields in naturally flat or leveled areas. The total length of the canal system is 200 – 2,000 m. The harvested water is used for growing high value crops, vegetables and fruit trees. Irrigated fields are divided into rectangular basins bordered by ridges to maximise water storage and minimise erosion risk.
Runoff and floodwater management requires preparedness for immediate action by the farmers: When a flood is expected in the ephemeral river, farmers rush to the diversion site and start erecting the embankment across the bed of the stream. Similarly, each famer starts to maintain the canal which leads water to his field. A schedule defines the date and time each farmer is allocated his turn to irrigate. When the water reaches the field, it is spread either through flooding or distributed in furrows which are opened and closed using a local tool.
The ratio between catchment area and production area is 10:1 – 100:1 or greater. While the diversion canals / ditches and basins for tree planting are permanent structures, basins for annual crops are seasonal. Soil fertility is improved by additional measures such as composting and mulching. Maintenance, including repairs to breaks along the canal and water conveying ditches, is needed every season before the onset of rains.

SLM measure	Structural
SLM group	Rainwater Harvesting
Land use type	Annual crops, tree crops
Degradation addressed	Loss of water, aridity; Loss of topsoil through erosion by water
Stage of intervention	Mitigation
Tolerance to climate change	Increased tolerance to drought and seasonal variations; sensitive to extreme flood events

Establishment activities

1. Construction of diversion canals with lateral embankments, from runoff source to the fields. Embankments are stabilised with stones – if possible (hand dug during dry season).
2. Seed bed preparation before the water is diverted to the fields: construction of rectangular basins separated by small bunds (0.3 m high; 0.3 m wide).
3. Watering the field for better seed germination. The field is watered before the seeds are planted otherwise germination will be affected.

Main canal: 3-4 m wide, 0.5-0.75 m high
Secondary canal: 2-3 m wide, 0.5 m high
Tertiary canal: 0.5-1 m wide

Maintenance / recurrent activities

1. Runoff management. This is essentially the activity of spreading water to the field which includes cleaning the canals for directing water to the field.
2. Seed bed preparation (reconstruction of basins is done every season, before the water is diverted to the field).
3. Regular maintenance / repairing of runoff diversion canals: scouring, removing sediment / silt, repairing breaks in the embankment.

Labour requirements

For establishment: high (very labour-intensive structures)
For maintenance: medium to high

Knowledge requirements

For advisors: medium
For land users: medium

Photo 1: Main canal for diverting flood water from seasonal rivers to the field. Lateral embankments are stabilised with stones.
Photo 2 and 3: Cropland prepared for floodwater farming: basins allow controlled flooding of the fields. In the background the river bed from which the water is extracted.
(All photos by Daniel Danano)

Case study area: Dire Dawa, Ethiopia

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour: 295 person-days	253
Equipment: shovels, hoes	24
Agricultural inputs	106
TOTAL	**383**
% of costs borne by land users	100%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 525 person-days	450
Equipment	64
Agricultural inputs: seeds	300
TOTAL	**814**
% of costs borne by land users	100%

Remarks: Establishment costs include the construction of diversion ditch, construction of blocks (irrigation basins); seeds and seedlings. Maintenance costs include the reconstruction of blocks / seedbed preparation; seeds and seedlings; weeding and cultivation; irrigation; harvest. Costs have been calculated assuming that 0.5 ha of the land is planted by fruit trees and 0.5 ha planted with vegetables. Daily wage cost of hired labor to implement SLM is 0.85 US$. All costs are met by the land users themselves.

Benefit-cost ratio

Inputs	short term	long term
Establishment	positive	very positive
Maintenance	very positive	very positive

Remarks: Net benefits are positive from the beginning due to rapid production increase.

Ecological conditions

- Climate: semi-arid (also suitable for arid areas)
- Average annual rainfall: 500-750 mm; erratic, not well distributed
- Soil parameters: good drainage, low organic matter
- Slope: flat to gentle (0-5%)
- Landform: footslopes and valley floors
- Altitude: 1,000-2000 m a.s.l.

Socio-economic conditions

- Size of land per household: 1-2 ha
- Type of land users: better-off small-scale farmers
- Population density: 150 persons/km^2
- Land ownership: state
- Land use rights: private
- Market orientation: mainly commercial, partly mixed (90% of vegetables and fruits are sold)
- Level of mechanisation: manual labour

Production / economic benefits

+++ Increased farm income (net benefit 1st year: 226 US$; from 4th year onwards: 711 US$)
+++ Increased crop yield (gross production value increases by 200% after 3 years and 400% after 10 years)
+++ Increased fodder production and increased fodder quality
+++ Increased wood production

Ecological benefits

+++ Increased soil moisture
+++ Increased infiltration
+++ Reduced runoff (from 50% to 5% of annual rainfall)
+++ Reduced soil loss (from 60 to 6 t/ha)
+++ Increased soil fertility

Socio-cultural benefits

+++ Community strengthening
+++ Improved conservation / erosion knowledge

Off-site benefits

+++ Reduced downstream flooding
+++ Increased stream flow in dry season
+++ Reduced downstream siltation

Weaknesses ➜ and how to overcome

- Increased labour constraints: construction of diversion ditches, preparation of irrigation basin and spreading the runoff water and regular maintenance / reconstruction of structures is very labour intensive ➜ providing improved farm tools could improve efficiency of operation, organising farmers in groups for sharing labor would curtail labor problems; Placing permanent structures at the diversion head (concrete) and paving ditches to improve channel stability would reduce maintenance activities.
- Social inequity: mainly better-off farmers apply the technology (due to high costs) ➜ providing credit solves financial problems and facilitating market would motivate land users to get more engaged in the business.
- Loss of land (through conservation structures) ➜ is outweighed by the high production benefits.

Adoption

100% of land users that have applied the technology, have done it wholly voluntarily, without any incentives except technical guidance. There is enough local skill and support to expand the technology.

Main contributors: Daniel Danano, Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia; ethiocat@ethionet.et
Key references: Danano, D. 2008; (unpublished): Soil and Water Conservation Practices for Sustainable Land Management in Ethiopia. Ethiocat.

Low-cost drip irrigation for vegetable production on a small plot in Niger. (William Critchley)

In a nutshell

Definition: A Smallholder Irrigation Management (SIM) unit is typically a plot covering an area less than 0.5 ha. SIM schemes may be managed either by an individual land user or by groups / communities.
The guiding principle of sustainable SIM is 'more crop per drop', in other words efficiency of water use. This can be achieved through more efficient (1) water collection and abstraction; (2) water storage; (3) distribution and; (4) water application in the field. Two main categories of SIM can be distinguished, traditional surface irrigation systems and recent micro-irrigation systems including drip irrigation. Micro-irrigation systems are commonly used for, and are very important in, the production of vegetables, fruits and flowers. More efficient water use can enhance production benefits remarkably. However, additional measures including soil fertility management, introduction of high value crops and appropriate pest and disease control are necessary for a substantial increase in production. As water resources in SSA are generally scarce and very unevenly distributed, any dream of widespread irrigation schemes is unrealistic. However, there is scope for improved irrigation management - making the most efficient use of precious water resources, especially for small-scale farming. Priority areas for SIM in SSA are in semi-arid and subhumid areas, where a small amount of irrigation water leads to a significant increase in yield - or at least a reduction in crop failure. Often there are possible synergies to be made by basing such schemes on water collected through rainwater harvesting. Therefore, SIM builds on the principles of supplementary irrigation, with rainfall as the principle source of water, and supplementary irrigation helping during dry spells and extending the growing period.
Applicability: SIM is most applicable to arid, semi-arid and subhumid areas. In water-scarce regions, the amount of irrigation water is limited and irrigation competes with other water demands.
Resilience to climate variability: SIM systems can enhance the resilience to droughts and temperature increase. The storage of excess rainfall and the efficient use of irrigation are critical in view of growing water scarcity, rising temperatures and climatic variability.
Main benefits: This system can increase incomes of the farmers by producing more, and higher-value, crops. Helping land users to move from subsistence farming to producing cash crops contributes to poverty reduction, primarily by enhancing the productivity of both labour and land. Agricultural production risks can be reduced, and food security enhanced.
Adoption and upscaling: The major constraint to smallholder irrigation is the availability of water. Financing (high costs of equipment), and the lack of a functioning market system to sell products, are further constraints. Therefore it is important that access to financial services is provided to land users. Land user group organisations can be a means to pool land users and resources and develop irrigation schemes.

Development issues addressed	
Preventing / reversing land degradation	+
Maintaining and improving food security	+++
Reducing rural poverty	++
Creating rural employment	++
Supporting gender equity / marginalised groups	++
Improving crop production	+++
Improving fodder production	+
Improving wood / fibre production	na
Improving non wood forest production	na
Preserving biodiversity	na
Improving soil resources (OM, nutrients)	+
Improving of water resources	-/+
Improving water productivity	+++
Natural disaster prevention / mitigation	+
Climate change mitigation / adaptation	-/+

Climate change mitigation	
Potential for C Sequestration (tonnes/ha/year)	0.15 (+/- 0.012)*
C Sequestration: above ground	+
C Sequestration: below ground	+

Climate change adaptation	
Resilience to extreme dry conditions	+
Resilience to variable rainfall	++
Resilience to extreme rain and wind storms	na
Resilience to rising temperatures and evaporation rates	+
Reducing risk of production failure	++

**for a duration of the first 10-20 years of changed land use management (Pretty et al., 2006)*

Origin and spread

Origin: Traditional SIM systems in SSA are mainly based on gravity systems using mountain streams. Spate irrigation is another traditional system, with a long history in the Horn of Africa. In the 1970s -1980s there was much investment in large-scale irrigation projects to intensify agriculture: these often ended in failure, because of either poor governance, or lack of maintenance, or both. In the 1980s investments in irrigation turned to a more integrated approach by financing small-scale irrigation with little or no government support. The use of drip irrigation systems has accelerated over the last decades with the mass production of plastic pipes. Initially it was a capital-intensive system. Recent innovations have helped to make drip irrigation more affordable to smallholders.
Mainly applied in: Burundi, Burkina Faso, Chad, Gambia, Guinea, Kenya, Mali, Niger, Nigeria, Senegal, Sierra Leone, Somalia, Tanzania, Zimbabwe

Spread of Smallholder Irrigation Management in SSA.

Principles and types

'More crop per drop' can be achieved through more efficient use of water:
(1) Efficient water abstraction, storage and distribution: SIM needs emphasis on efficient water storage, abstraction and distribution to the field. Water sources for irrigation can be rivers, lakes, groundwater, or water collected through rainwater harvesting systems (see RWH group). The water can be either abstracted through pumps or wells, or it can be gravity-fed. Treadle pumps, which are food-operated water lifting devices, have been very successfully introduced in SSA for the production of vegetables. More efficient water distribution can be achieved through the usage of pipelines instead of open water channels.
(2) Efficient water application in the field: In a SIM-system the water is used efficiently by applying appropriate quantities at strategic times, principally through providing supplementary irrigation water at particular growth stages. Excessive flooding can be harmful, as it may lead to nutrient leaching, as well as inducing greater evaporation and salinisation. The application of too little water is also wasteful, since it will fail to provide the desired benefits. Under the 'deficit irrigation method' crops are exposed to different levels of water stress resulting in enhanced root development - and thereby substantial saving of water can be achieved while maximum yields can be almost attained.
a) Micro-irrigation techniques are promising systems for increased water use efficiency. Within micro-irrigation, a small volume of water is applied at frequent intervals to the spot where the roots are concentrated. Micro-irrigation techniques are gaining popularity among small-scale farmers, especially those systems using water harvested in tanks and small ponds. The most common micro-irrigation system is drip irrigation.
In a **drip irrigation system**, water flows under pressure through a filter into drip pipes, with emitters located at variable spacings. Water is discharged directly onto the soil near the plants. Drip lines should be placed close to the plants to avoid salt accumulation in the root zone, and to minimise water loss. Fertilizer and nutrients can be applied easily, and more precisely, through the system.
b) Surface irrigation is the application of water by gravity flow to the surface of the field. Either the entire field is flooded, or the water is led into basins, or fed into furrows, or strips of land (borders). Surface irrigation is the main traditional irrigation method and still plays a significant role in SSA. An example is:
Spate irrigation: Floodwater diversion or spate irrigation techniques divert the water from its natural course. Storm-floods are harvested from rainfall-rich highlands, and diverted into levelled basins in the dry lowlands. Floodwater is channelled through a network of different channels. Collection areas may range from anything between a few hectares to over 25,000 ha. The schemes are expensive to construct and difficult to maintain due to frequent bund breakages during floods. Spate irrigation is mainly applied in Ethiopia, Eritrea, Kenya, Senegal, Somalia and Sudan.
Informal irrigation can be defined as the irrigation sector established purely by land users without public funding (often synonymously with smallholder irrigation). Informal irrigation is widespread in urban and peri-urban agriculture, especially in West Africa. It is common in market gardening of cash crops. Intensive irrigation relies mainly on watering cans, due to its low investments costs and precise water application, yet it is labour intensive. The value of urban agriculture and informal irrigation is still underestimated in SSA.

Top: Water distribution for irrigation, Kenya. (Hanspeter Liniger)
Middle: Large private vegetable producer using watering cans for irrigation, Senegal. (Christoph Studer)
Bottom: Detail of a drip irrigation system: water from the pipe is being emitted directly onto the soil close to the plant, Niger. (William Critchley)

Applicability

Land degradation addressed

Water degradation: aridification – decrease of average soil moisture content, overuse / over-abstraction of surface and groundwater / aquifer level due to inefficient water use and too high demand on irrigation water

Physical soil deterioration: waterlogging, sealing and crusting through inappropriate irrigation management

Chemical soil deterioration: salinisation of soil through inappropriate irrigation management and through bad quality of irrigation water

Unsuitable for areas prone to salinisation where salts cannot be washed out by drainage.

Land use

Mainly used on cropland and mixed land and in homegardens for food and cash crops (vegetables, fruit trees, etc.), rice, cotton, etc.

Sometimes used for establishment of tree plantations.

Micro-irrigation system mainly used for vegetables, fruits and cash crops or for tree seedlings and establishment of trees.

Spate irrigation is used mainly for cereal crops.

Ecological conditions

Climate: Mainly for semi-arid and subhumid areas, partly for arid areas. Smallholder irrigation systems are valid options in almost all types of agro-ecological zones. They are naturally most relevant in areas where water is a constraint to crop production, and where water resources are limited, very variable or overused: thus in semi-arid to subhumid zones. Drip irrigation systems are very suitable for water-scarce areas. In arid areas with annual rainfall of less than 500 mm, irrigation management is mainly related to permanent rivers, based on water harvesting methods, or withdrawals from groundwater.

Terrain and landscape: Spate irrigation requires a highland catchment area which supplies runoff in seasonal or ephemeral rivers. Drip irrigation can irrigate sloping land and even quite steep slopes.

Soils: No restrictions, apart from soils with high sodium (Na) content (sodic soils); needs good management on heavy clays due to risk of waterlogging. Drip irrigation can reduce or eliminate runoff and deep percolation, making it possible to irrigate difficult soils – e.g. crusting or porous soils, through frequent and controlled application of water.

Socio-economic conditions

Farming system and level of mechanisation: Traditional irrigation systems are mainly applied on small-scale farms. Modern irrigation systems were used originally on large-scale farms. The newly popularised system of drip irrigation, for example, is now also affordable and suitable for small-scale farming due to the development of smaller units and kits for smaller areas, tended by hand. Smallholder irrigation systems are mainly maintained with manual labour.

Market orientation: SIM can be used for subsistence and small-scale farming. Irrigation can help farmers to move from solely subsistence to a mixed subsistence / commercial system.

Land ownership and land use / water rights: SIM-systems are normally privately owned by the land users or land user groups, therefore secure rights and full control over water are essential for the users. Additional permits for the use of scarce water resources may be needed.

Skill / knowledge requirements: Needs high level of knowledge for the establishment, and also for the maintenance, of the system (especially micro-irrigation systems). Timing and amount of water application requires considerable skill.

Labour requirements: Depending on the system, the labour requirements are medium to high; a spate irrigation system needs higher labour inputs for establishment than micro-irrigation. The maintenance of a drip irrigation system can be very demanding, but the labour days needed for watering can be significantly reduced through the implementation of drip irrigation, compared to watering with cans.

Key: High / Moderate / Low / Insignificant

Land degradation

Erosion by water	Insignificant
Erosion by wind	Insignificant
Chemical degradation	Moderate
Physical degradation	High
Biological degradation	Insignificant
Water degradation	High

Land use

Cropland	High
Grazing land	Insignificant
Forests / woodlands	Insignificant
Mixed land use	Moderate
Other	Insignificant

Climate

Humid	Insignificant
Subhumid	High
Semi-arid	High
Arid	Moderate

Average rainfall (mm)

> 3000	Insignificant
2000-3000	Insignificant
1500-2000	Moderate
1000-1500	High
750-1000	High
500-750	High
250-500	High
< 250	Insignificant

Slopes (%)

very steep (>60)	Insignificant
steep (30-60)	Insignificant
hilly (16-30)	Moderate
rolling (8-16)	Moderate
moderate (5-8)	High
gentle (2-5)	High
flat (0-2)	High

Farm size

Small scale	High
Medium scale	Moderate
Large scale	Insignificant

Land ownership

State	Low
Company	High
Community	Moderate
Individual, not titled	Moderate
Individual, titled	High

Mechanisation

Manual labour	High
Animal traction	Low
Mechanised	Low

Market orientation

Subsistence	Low
Mixed	High
Commercial	Moderate

Required labour

High	High
Medium	Moderate
Low	Insignificant

Required know-how

High	High
Medium	Insignificant
Low	Insignificant

Economics

Establishment and maintenance costs

Establishment costs for SIM-systems vary considerably. Drip irrigation systems carry relatively high investment costs. Some traditional systems are (or were) high in initial labour – where for example intricate networks of channels brought water down from highland streams. Maintenance of the latter has almost always been carried out with no external support. If the costs for a drip irrigation system are worked out per hectare then the prices appear high. Yet it is the low incremental cost that allows land users to start on a small area (e.g. for horticultural production). The costs for small-scale drip kits have decreased dramatically which makes them now affordable for small-scale users. Even so it still requires initial investment and hence access to micro-credit: this means it is not a possibility for the poorest of land users. Land user groups provide an opportunity for joint investment in the equipment.

SIM-system	Establishment costs
Drip irrigation: Bucket system (for home gardens) Drum kit irrigation system Farm kit drip irrigation	 5 US$ for 50m² ➜ 2,000 US$ per ha 10 US$ for 40 m² ➜ 2,500 US$ per ha 25 US$ for 125 m² ➜ 2,000 US$ per ha 424 US$ with 1,000 litre tank, for 2,500 plants per one-eight acre (= 500 m²) 150–240 US$ for 1,000 m² ➜ 1,500 – 2,400 US$ per ha
Treadle pump	50-120 US$ per pump (for about 0.4 ha)
Spate irrigation systems	1,000 US$/ha

(Sources: FAO, 2001; GTZ, 2001; Grid, 2008)

Maintenance costs for SIM cannot be neglected: drip irrigation systems, especially, need careful maintenance. However, the implementation of a drip irrigation system in place of watering with cans lessens the labour input, reduces the water used and therefore the fuel costs. An example based on drip irrigation introduced in an African Market Garden system (AMG: see case study) has shown a reduction in workload from 240 man hours when irrigating with watering cans compared to 90 man hours with drip irrigation in the AMG system.

Production benefits

	Yield without SLM (kg/m²)	Yield with SLM (kg/m²)	Yield gain (%)
	Traditional irrigation	AMG* system	
Lettuce (Niger)	1.14	1.95	+ 70%
Onion (Ghana)	1.21	1.65	+ 36%

**AMG: African Market Garden system based on drip irrigation and crop species selection (Woltering, et al., 2009).*

Comment: The figures presented above show the higher crop yield for the AMG system compared to the traditional system with watering cans. Beside the improved irrigation system the crop varieties selected also influence the yield.

Benefit-Cost ratio

Irrigation system	short term	long term	quantitative
Drip irrigation	+	+++	AMG* (50 m²), Burkina Faso: Return to labour: 12.6 US$/day Return to land: 1.7 US$/m²
Bucket kit	+	+++	Income / cost per bucket kit, Kenya: 26-40/15 US$
Spate irrigation	++	+++	
Overall	+/++	+++	

– – negative; – slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive;
**AMG: African Market Garden system based on drip irrigation and crop species selection (Source: Mati, 2005; Woltering, et al., 2009)*

Comment: The AMG system clearly shows the profitability of drip irrigation, which is around double that of traditional irrigated gardens. The returns to labour are about three times higher for the AMG than for the traditional system.

Example: *A simple bucket system costing US$ 10, allowing the irrigation of 40 m², represents an investment of US$ 2,500 per ha, which, depreciated over 2-3 years, results in annual depreciation costs of US$ 833 – 1,250 per ha. In comparison, some gravity-based communal schemes providing water for an irrigation area of 100 ha with high initial investment costs can be depreciated over 5 years at a rate of US$ 400/ha. Despite the large difference in investment costs per ha, the small units are on a par with the larger schemes with respect to the financial income they are able to generate (GTZ, 2006).*

Example: Zambia
In Zambia, treadle pumps could significantly increase incomes of small-scale land users. With the former used bucket irrigation system the income achieved was about 125 US$ per 0.25 ha of land, whereas with treadle pumps the income increased to 850-1,700 US$. This was attributed not only to increased crop yields, but also to the greater area of land irrigated. Cropping intensity rose in some cases by 300% with an associated increase in crop varieties. Because of the better water availability land users were more willing to invest in new crops (FAO, 2001).

Example: African Market Gardens in the North of Benin
Studies conducted through ICRISAT and partner organisations in West Africa have clearly shown the high profitability of African Market Gardens (AMG). The profitability of AMG is around double that of vegetable gardens irrigated with traditional methods. Returns to labour are more than three times higher for AMG and the investment can be paid back in little more than one year. The payback period can even be shorter if the investments are made through a land users / commune group. (Woltering, et al., 2009)

Impacts

Benefits	Land users / community level	Watershed / landscape level	National / global level
Production	+++ informal irrigation in urban areas helps to diversity livelihoods and diets of the poor dwellers +++ higher crop yields ++ enhanced productivity of labour and land ++ increased diversity of cropping	++ reduced risk of crop failure	+++ improved food and water security
Economic	+++ increased income and new income streams + reduced labour (through reduction of weeds, because no watering between plants and less time needed for watering)	++ stimulation of economic growth ++ new labour opportunities for landless labourers + less damage to off-site infra-structure	+++ improved livelihood and well-being
Ecological	++ through more efficient water use reduced pressure on water resources ++ allows to produce crops in the off-season if water storage available + micro-irrigation: reduced salinisation hazard: through reduced evaporation and salt accumulation on soil surface + reduced soil erosion (by water / wind) + improved soil cover + increased soil fertility + biodiversity enhancement + improved micro-climate	++ increased water efficiency and reduced pressure on water resources	
Socio-cultural	++ strong gender component, as marketing of vegetables is the domain of women	+ increased awareness for environmental 'health' + attractive landscape	+ protecting national heritage

	Constraints	How to overcome
Production	• Lack of reliable water supply • Land users tend to use more water than needed by using a micro-irrigation system, since water can be applied more easily	➜ storage facilities (but has additional cost) ➜ needs good training of the land users
Economic	• Lack of market access and incentives for agricultural intensification • Lack of market for low cost irrigation material • High investment costs especially a problem for poor land users • Requires a high level of technical knowledge also for maintenance of the system	➜ promoting markets for smallholder irrigation systems ➜ access to credits and financial support to improve the ability to invest in smallholder irrigation systems
Ecological	• Abstraction / overuse of surface water and non-renewable ground and / or fossil water • Waterlogging and salinisation • If dependant on water harvesting or surface water during dry years / periods, water supply for irrigation can be threatened • Over-irrigation facilitates the development of diseases, weed growth and nutrient leaching Drip irrigation: • Salt accumulation at root zone (especially in areas with rainfall <100 mm) • Only a fraction of root zone is wetted, is more susceptible, and depends on the continuous operation of the system	➜ use of improved rainwater harvesting systems to collect and store additional irrigation water ➜ good crop rotation, appropriate irrigation practices, balance supply and demand of water ➜ needs good technical knowledge and appropriate maintenance of the system ➜ regular leaching of salts and drainage for removal of salts is necessary
Socio-cultural	– Over-abstraction of surface and groundwater resources can lead to a decline of river flows and groundwater table and endangering supply of drinking water – Conflicts over water	➜ specialists providing technical and economic information are needed ➜ proper planning and regional assessment of water resources as well as restricted allocation of irrigation water

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Adoption and upscaling

Adoption rate
SSA shows one of the lowest degrees of investment in irrigation among developing regions, and recent surveys do not show any sign of change, the annual increase in irrigation being slightly more than 1% between 1995 –2005.

Upscaling
The adoption of small-scale irrigation systems will also be determined by the capacity of land users to take risks in the uptake and investments with a new technology. Therefore the following aspects are crucial:

Reliable water supply: The access to reliable supply of water is often the major constraint to irrigation.

Profitability: The benefit-cost ratio must make it worthwhile for land users to invest in irrigation. For poor land users the high investment cost and the payback time pose a major obstacle.

Access to financial services: The financing and managing of irrigation systems need to be market-driven and are to a large degree the responsibility of smallholders. The self-financing capacity of farmers needs to be strengthened and credit must be easy accessible to smallholders. Land user groups / community organisations can be an opportunity for poor land users to receive credit and to make the initial investment.

Access to markets and infrastructure: Functioning markets and market access is a prerequisite for the success of SIM. Irrigation can help subsistence land users to become more market-oriented.

Market for low-cost drip irrigation systems: Even though a market very often exists for equipment generally, low-cost drip irrigation systems may be hard to obtain. Therefore, setting up a working supply chain and ensuring sufficient manufacturing capacity is essential.

Technical support and capacity development: The utilisation of the full potential of irrigation production needs adequate training and technical support for the land users also for appropriate water application and maintenance of the system. Competent specialists providing technical and economic information are needed.

Policy: Usually a Ministry of Agriculture is separate from a Ministry of Water, which often leads to administrative confusion and administrative hurdles. The water and agricultural sector must be coordinated.

If an irrigation system is used in common, the number of users sharing the infrastructure should be low. Operational simplicity is a major criterion for the success of small-scale community-based irrigation schemes.

Comment: The dream of many land users in SSA to increase production and income with irrigation is limited by the availability of water. Already today, scarce water resources are often overused. Therefore, the main aim should be to improve water use efficiency and to develop more decentralised smaller irrigation systems without causing land or water degradation.

Incentives for adoption
For SIM to be used by individuals these ideally should not be subsidised but should be self-financed by land users. For that reason, the access to micro-credit must be ensured. Yet, SIM techniques are still only accessible to land users who can afford to buy them or to access micro-credit. Therefore poorest land users need appropriate financial and technical support for the establishment of a SIM system.

Enabling environment: key factors for adoption	
Inputs, material incentives, credits	+++
Training and education	++
Land tenure, secure land use rights	+++
Access to markets	+++
Research	++
Infrastructure	++

Example: Kenya
In the study conducted by Kulecho and Weatherhead (2006) NGOs were asked what they considered as the main problems for smallholder irrigation in Kenya. The systems used were mainly drip, furrow and sprinkler systems. The results showed that the highest number of responses were related to the problem of crop marketing, low-cost drip irrigation maintenance, followed by water supply problems. The report clearly showed that farmers need adequate technical support, reliable water supplies, and affordable access to markets if they are to maximise the economic and poverty-reducing benefits of low-cost drip systems.

Example: Burkina Faso and Niger
ICRISAT has introduced the African Market Garden (AMG) system as a commercial irrigation and production system in Niger. There was little follow-up and in most cases non-educated land users were left on their own to operate the systems, which resulted in zero maintenance. Only 4 years after the implementation 20% of the systems were still found operational. The producers who abandoned the systems found that there were no clear savings in labour and water. Based on these experiences a new project started in Burkina Faso. This time only the wealthier small-scale farmers were approached and they paid 70% of the investments. Most of the systems are still operational. It demonstrates that the more educated and the wealthier a producer is, the more likely he / she is to adopt small-scale drip irrigation (Woltering, et al., 2009).

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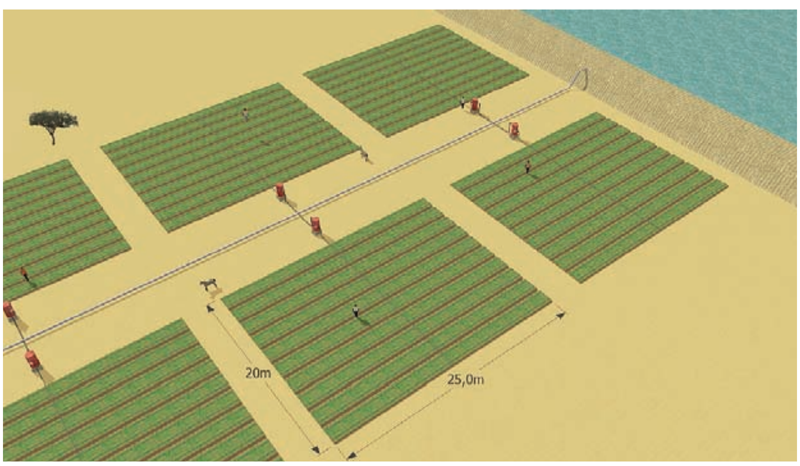
AFRICAN MARKET GARDENS - SENEGAL

The African Market Garden (AMG) is a horticultural production system based on low-pressure drip irrigation. According to the level of experience, market orientation or social structure of the land users, four different AMG models have been developed. This case study focuses on the 'Cluster System' which is suitable for an organised group of independent vegetable producers sharing a common water delivery system.

From a central source, water is distributed through a pipe network to a cluster of plots. Each farmer operates a 1,000 m^2 unit, and each is equipped with an elevated 200 litre barrel and a standard irrigation kit, including a tap, filter and thick-tube drip laterals. Minimal size of an AMG unit should be 500 m^2. Affordable high-quality material is used and the design and operation is simple. The barrel also serves as a fertilizer tank. A float ensures a constant pressure head. Water supply is calculated by the time needed for delivery of the daily water dosage, or through the use of water dosing valves. Producers have individual control of water use. Since the AMG requires only 1 meter pressure for operation, it can draw on low-capacity renewable energy sources such as elevated dams, solar pumps or reservoirs. To supply an area of 50,000 m^2 with 8 mm/day in the hot season a 400 m^3-reservoir is required. The crops are planted on elevated beds. Water mixed with urea as fertilizer is applied daily. Drip irrigation improves growing conditions for crops while at the same time saving labor, water and other inputs.

AMG is promoted as a holistic management package, integrating all aspects of production, post-harvest and marketing in one system. This includes the use of improved vegetable varieties, improved crop husbandry, integrated pest management, as well as improved storage, processing and marketing of products, and improved access to inputs.



SLM measure	Agronomic
SLM group	Smallholder Irrigation Management
Land use type	Annual crops: vegetables; Tree crops: fruit trees
Degradation addressed	na
Stage of intervention	Prevention
Tolerance to climate change	AMG especially suitable for seasons with high evapotranspiration demand, because AMG permits daily irrigation that eases water stress

Establishment activities

1. Build concrete reservoir.
2. Drill borehole (110 mm diameter; 12 m deep, hand drilled).
3. Install motor pump and tubes to connect well with reservoir.
4. Install drip kit with tap, filter and drip laterals (8-16 mm in diameter).
5. Establish a fence to protect the garden.

Maintenance / recurrent activities

1. Prepare elevated beds with a basic dressing of 4 kg/m^2 manure and 0.1 kg/m^2 NPK fertilizer biannually.
2. Add urea to irrigation water (concentration: 50-100 ppm N).
3. Operate water supply system.

Labour requirements

For establishment: high
For maintenance: low

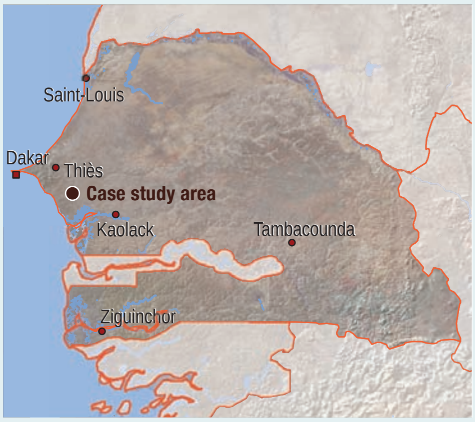
Knowledge requirements

For advisors: high
For land users: high

Remark: Installation of the system requires basic knowledge on engineering for the sizing of the PVC distribution network.

Photo 1: AMG system with elevated barrels for irrigation of cash crops (okra) through drip laterals. (ICRISAT)
Technical drawing: Cluster system with several AMG plots connected to a central water source - in this case a small elevated dam. (ICRISAT)

Case study area: Ngoyé Ndioffogor and Mbassis Tatadem, Senegal



Establishment inputs and costs per unit

Inputs	Costs (US$)
Drip system	300
Oil drum (200 l)	56
Well / borehole	16
Motor pump (3 hp)	34
Farming tools	65
Fence	25
PVC connections	79
TOTAL	**575**

Maintenance inputs and costs per unit and year

Inputs	Costs (US$)
Labour, fuel and agricultural inputs	510
TOTAL	**510**

Remarks: A unit corresponds to the area irrigated by one producer (= 500 m^2). Establishment costs include labour inputs (2 US$ per person-day). Annual maintenance costs include labour, fuel and agricultural inputs (e.g. fertilizer, seeds; based on ICRISAT recommended rates). For a 1,000 m^2-unit prices are doubled (except for tools and fence).

Benefit-cost ratio

Inputs	short term	long term
Establishment	slightly positive	very positive
Maintenance	very positive	very positive

Remarks: Payback period is only 6 months. Net income per farmer after all deduction is about US$ 1,000 per year. The profitability of the AMG is around double that of vegetable gardens irrigated with traditional methods.

Ecological conditions

- Climate: semi-arid
- Average annual rainfall: 400-500 mm
- Soil parameters: sandy soils, low fertility and organic matter content
- Slope: flat (0-2%)
- Landform: plains
- Altitude: no data

Socio-economic conditions

- Size of land per household: no data
- Type of land user: small to medium-scale, land user groups, poor to average level of wealth
- Land ownership: individual (titled)
- Land use rights: individual - secure land use rights are a precondition
- Level of mechanisation: manual labour / mechanised
- Market orientation: commercial
- AMG is suitable for urban / periurban areas where producers have access to credit, markets, technical support
- Strong organisation in groups is important for the maintenance of the system and for access to training / backstopping

Production / economic benefits

+++ Reduced production costs: costs for drip irrigated gardens are 50% lower than for traditional irrigated gardens due to savings in labour, water and consequently in fuel
+++ Reduced workload: total workload for AMG is 11.5 man-days compared to 30 man-days in traditional irrigation system
+++ Increased income due to doubled profits from vegetable production (compared to traditional irrigation methods)

Ecological benefits

+++ Improved water availability / reduced pressure on water resources
+++ Reduced evaporation / effective use of water due to accurate and equal distribution of water at optimal rates
+++ Effective application of fertilizer with the water

Socio-cultural benefits

+++ Improved nutrition and food security through year-round availability of quality vegetables and fruits
+++ Improved knowledge on irrigation techniques / horticulture
+++ Improved organisation (farmer associations, user groups, etc.)

Weaknesses ➜ and how to overcome

- Irrigated vegetable production is a capital intensive undertaking ➜ sharing infrastructure, land and water through producer groups can cut investment costs by 60% per unit area. Set-up and operation costs further decrease if producer groups can use communally owned infrastructure and / or alternative energy sources (e.g. elevated dams, solar pumps, artesian well).
- The AMG system is not suitable for farmers with limited access to knowledge, marketing and services ➜ improve access to markets and training programs (for extensionists and farmers); guarantee technical assistance during 2-3 years; target the system to educated producers who make a living out of vegetable production. Set up AMG service and demonstration centres offering credit, farm inputs, marketing support, training and technical advice.

Adoption

AMG is spreading fast in Senegal and Burkina Faso. Cost reduction (e.g. alternative energy sources), collective action and intensive training / backstopping are very important provisions for successful adoption. Upscaling of AMG in dry West Africa will depend on access to technology, inputs, knowledge and organisation, and a conducive institutional environment.

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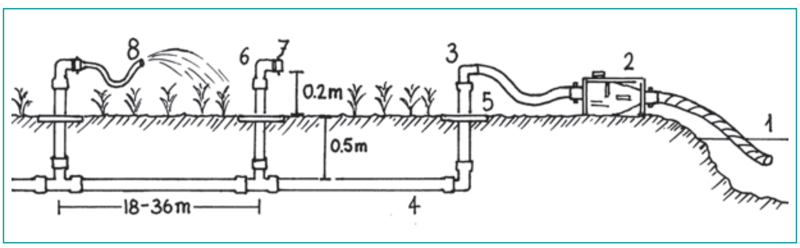
Key references: Woltering L., D. Pasternak and J. Ndjeunga. 2009. The African Market Garden: Development of an Integrated Horticultural Production System for Smallholder Producers in West Africa – Draft Submitted to Irrigation and Drainage 21-10-2009 ■ ICRISAT. 2009. The African Market Garden - Advanced Horticulture for the Poor (Flyer).

LOW-PRESSURE IRRIGATION SYSTEM 'CALIFORNIAN' - SENEGAL

The low pressure pipe distribution system called 'Californian' has proven to be a very efficient irrigation system for smallholder farmers group in Africa. The principle of the Californian system is to convey water to the crops through fixed underground rigid PVC pipes (40–75 mm diameter). The pipe network is buried at 0.50 m depth to avoid deterioration by UV radiation and agricultural practices. Risers with hydrants are fixed to those rigid pipes at regular distance (18-36 m). To each riser a 14 m long flexible hose is attached which can be dragged around to irrigate the individual plots and crops. The installation of the pipe network can be made locally by plumbers. Water is supplied through a pump (manual, pedal or small motor) from a well, a reservoir or a river. From the intake water is conveyed to the highest point of the plot which allows the conveyance to the field's most distant point (irrespective of topographical conditions - upslope or downslope).
The system is remarkably efficient in sandy or salty soils. It is adapted to small–scale farming especially for vegetable crops, rice and tree crops and is suitable for areas ranging between 0.25 - 1 ha; one riser irrigates an area of 500-1000 m^2. The system as such does not require maintenance. In case of deterioration of pipes or fittings, the farmer can easily fix the problem himself or with the assistance of a local plumber. The estimated life expectancy for the Californian system is 6-10 years in West African conditions. Ideal conditions for transfer / adoption of the technology include: (1) availability of shallow aquifers, and other water sources; (2) occurrence of sandy soils and sandy clay soils; (3) clearly defined land legislation and tenure; (4) access to markets and to microfinance institutions.



SLM measure	Agronomic
SLM group	Smallholder Irrigation Management
Land use type	Annual cropping
Degradation addressed	na
Stage of intervention	Prevention
Tolerance to climate change	High tolerance as long as water source is not depleted

Establishment activities

1. Layout of pipe network by putting stakes along the line to indicate the orientation of the canal to be dug.
2. Excavate network of canals (0.2 m wide, 0.5 m deep; straight and regular). In sandy soil the interval between risers is 30 m x 18 m or 36 m x 18 m (intervals are multiples of 6 m = PVC pipe unit length). Density of risers is 10 -15 risers/ha.
3. Install the pipes into the open canals, fittings are assembled by sticking.
4. Install hydrants composed by a 0.2 m high riser, a PVC elbow and a locally made flow control device (plug); the risers are anchored in the soil through a small concrete slab.
5. Put the pipe under flow condition to verify the water tightness of the system.
6. Bury the canals.
7. Protect risers from sun.

Maintenance / recurrent activities

1. Before starting to pump it is recommended to let open one of the hydrants in order to avoid excessive pressure and blasting of pipes.
2. In case of deterioration of the pipes or fittings, land users can easily fix the problem themselves or request the intervention of a local plumber.

Labour requirements

For establishment: medium
For maintenance: low

Knowledge requirements

For advisors: high
For land users: high

Remark: Technical assistance needed for design, installation and operation of the system; installation of pipes is quick and easy; no need for topographical survey.

Photo 1: Hand pump for supply of irrigation water;
Photo 2: Pipes for the distribution of irrigation water are buried in 0.5 m deep canals;
Photo 3: Growing onions on an irrigated plot (All photos by Sourakata Bangoura)
Technical drawing: Dimensions and main components of the low-pressure irrigation system: (1) water source; (2) manual or motor pump; (3) input hydrant; (4) rigid PVC pipes; (5) small concrete slab; (6) elbow; (7) plug; (8) flexible hose for irrigation.

Case study area: Diourbel, Senegal

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour	50
Equipment/tools	no data
Construction material	1333
TOTAL	**1383**
% of costs borne by land users	0%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour, equipment, construction material	no data
TOTAL	**no data**

Remarks: If soil is not sandy labour input for establishment increases. Hand or treadle pumps are provided by the project. Motor pumps (with pump capacity 2 HP) increase costs for establishment and maintenance (fuel) but reduce labour inputs for operation.

Benefit-cost ratio

Inputs	short term	long term
Establishment	positive	very positive
Maintenance	positive	positive

Remarks: The estimated life expectancy for the Californian system is 6-10 years in the West African conditions.

Adoption

Totally 468 farmers (64% of them women) have adopted the technology. Inputs were paid by project. There is high demand for the technology. Full participation of stakeholders in the whole project process and the involvement of local leaders, local NGOs and private companies are prerequisites for successful implementation.

Ecological conditions

- Climate: semi-arid; sudano-sahelian, 9 months dry period: Oct.-June
- Average annual rainfall: 450 mm
- Soil parameters: sandy soils, with low organic matter content, low fertility, good drainage (tropical ferralitic soils)
- Slope: flat or gentle (0-5%)
- Landform: plains
- Altitude: 25 m a.s.l.
- Availability of shallow aquifers, and other water sources is crucial; sandy soils and sandy-clay soils are suitable.

Socio-economic conditions

- Size of land per household: 0.5 ha
- Type of land user: poor small-scale farmers, implemented individually or within farmer groups
- Population density: no data
- Land ownership: mostly individual
- Land use rights: mostly individual
- Level of mechanisation: mostly manual labour and animal traction
- Market orientation: mixed (subsistence and commercial)
- Strong local leadership, long term land use rights and external funding or access to microfinance institutions are preconditions.

Production / economic benefits

+++ Increased crop yield (in combination with improved agricultural inputs (fertilizer, pesticides, seeds)
+++ Increased production area (from 0.1 to 2 ha per farmer group)
+++ Reduced risk of production failure
+++ Increased drinking / household water availability (from < 10 to 20 liters/ person-days)
+++ Increased irrigation water availability
+++ Increased farm income and diversification of income sources
++ Increased product diversification

Ecological benefits

+++ Increased water quantity
+++ Reduced hazard towards adverse events (droughts)
+++ Increased plant diversity
+++ Increased soil moisture
++ Increased water quality
++ Reduced surface runoff
++ Reduced salinity
++ Improved soil cover and increased biomass

Socio-cultural benefits

+++ Improved cultural opportunities (pilgrimage to Mecca, marriages, etc.)
+++ Community institution strengthening
+++ Conflict mitigation (group management of irrigation facilities)
+++ Improved food security / self-sufficiency
++ Improved situation of socially and economically disadvantaged groups
++ Improved health

Weaknesses

- Initial investment cost of construction material and equipments.
- Breakage of riser pipes.
- Scarcity of surface water resources, poor water quality (salinity), low water discharge from the shallow wells and boreholes limit the applicability of the system.
- Lack of farmers knowledge on irrigation techniques and lack of qualified personnel for training and supervision hinder successful implementation.

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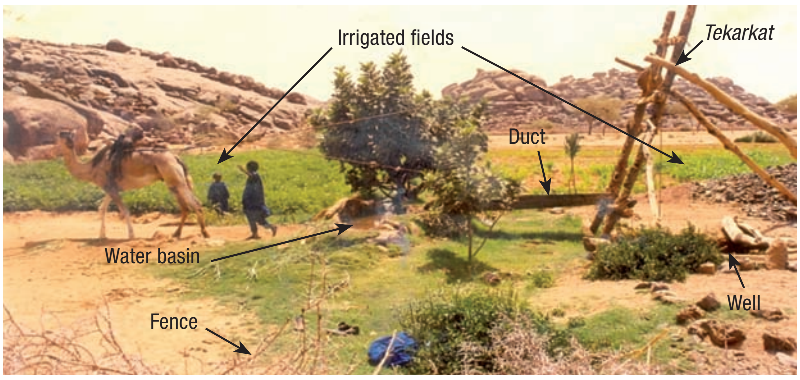
IRRIGATED OASIS GARDENS - NIGER

In the Oasis of Timia in the Aïr, small irrigated gardens (< 0.3 ha) have been used for over a century, producing dates and tree crops (figs, citrus, cherries, etc.) for sale and cereals for consumption (wheat, maize and pearl millet). With the onion boom in the 1990s, the establishment of new gardens grew dramatically. The new gardens cover a bigger area (0.5 - 1 ha) and focus on cash crops - mainly onions, but also potatoes and garlic. Gardens are fenced using branches from acacia trees. The water supply system in most cases is based on traditional wells with an animal-drawn scoop. The wells are less than 20 meters deep and generally built without a casing. Local experts were trained by GTZ project staff in well construction and maintenance. Modern motor pumps have recently become common and are used in new gardens. Water is conveyed to the plots through a hand-dug network of distribution channels. The channels are lined with clay and stones to minimise water loss through infiltration, evaporation, or breaching. Irrigating a whole garden takes about two hours.
There are two cropping seasons per year: the rainy season (June-September) with staple crops such as maize and millet; and the dry / cold season (October-February) with wheat-barley associations and cash crops such as onions, garlic, tomatoes and vegetables. Fruit trees covering up to a fifth of the gardens; one section of the garden is reserved for keeping small ruminants. Agricultural residues are used as fodder and manure produced by livestock ensures fertility of gardens in combination with inorganic fertilizers. Traditional techniques (local plants, ash, etc.) are used for pest management. Seed production and selection is done strictly locally.



SLM measure	Structural and vegetative
SLM group	Smallholder Irrigation Management
Land use type	Annual cropping, Tree cropping
Degradation addressed	Chemical and biological degradation of soil; Soil erosion by water and wind
Stage of intervention	Rehabilitation and mitigation
Tolerance to climate change	Technology is sensitive to drought, temperature increase, floods and storms

Establishment activities

1. Identify and demarcate of a free area to be converted into a garden. Fence area with acacia branches and living hedge.
2. Establish a traditional or cement well, max. 2 m wide and 15-20 m deep (contract with local well builder) in the middle of the field.
3. Installation of traditional water conveyance system (*Tekarkat*): wooden poles hold a pulley which conducts a rope with a scoop for extraction of water from the well. The system is powered by a dromedary. A 5 m duct (palm stem or iron sheet) conducts the water to a small reservoir.
4. Mark and dig irrigation canal system and basins for crop cultivation (8 m^2): Main canal and secondary canals (perpendicular to main canal) are reinforced with clay or stones.
5. Purchase inputs (local market): seeds, seedlings, fertilizer, tools.
6. Plant fruit trees.

Activities 1. and 4. are done collectively. All activities are carried out by manual labour.

Maintenance / recurrent activities

1. Maintenance of fence: replace missing branches; plant new tree seedlings to reinforce the living hedge (biannually).
2. Irrigation (daily).
3. Maintenance of *Tekarkat* and canal system: control (and replace) poles; periodic weeding, cleaning, repair leaks and improve lining with clay/stones (biannually, after harvest).
4. Field preparation and application of organic manure (beginning of each cropping season).
5. Maintenance of well: cleaning (hot season), reinforce walls with cement (if needed).
6. Feeding draught animal using natural grassland and crop residues.

Labour requirements

For establishment: medium to high
For maintenance: medium to high

Knowledge requirements

For advisors: medium to high
For land users: low (indigenous knowledge)

Photo 1: Components of an irrigated oasis garden with a traditional *Tekarkat* water supply system. The dromedary pulls up the water filled scoop.
Photo 2: *Tekarkat* established in an oasis North of Tahoua.
Photo 3: Irrigated gardens in Timia. (All photos by Abdoulaye Sambo Soumaila)

Case study area: Timia oasis, Aïr, Niger

Establishment inputs and costs per 0.5 ha

Inputs	Costs (US$)
Labour: 90 person-days	180
Land (opportunity costs)	400
Equipment: traditional well and *tekarkat*	500
camel / dromedary	400
Other equipment:	200
Agricultural inputs: seedlings (50)	200
TOTAL	**1880**
% of costs borne by land users	100%

Maintenance inputs and costs per 0.5 ha per year

Inputs	Costs (US$)
Labor: 104 person-days	208
Equipment: traditional well and *tekarkat*	100
camel (fodder, health)	1460
Other equipment:	100
Agricultural inputs: seedlings, organic fertilizer	240
TOTAL	**2108**
% of costs borne by land users	100%

Remarks: Cost calculation is based on local land prices and traditional irrigation systems. Maintenance costs include also fodder (for draught animal) and organic manure.

Benefit-cost ratio

Inputs	short term	long term
Establishment	very positive	vey positive
Maintenance	very positive	very positive

Remarks: The technology serves a double purpose: food security and income generation.

Ecological conditions

- Climate: arid
- Average annual rainfall: <120 mm
- Soil parameters: sandy soils, with usually good drainage, medium water storage capacity, medium soil fertility and soil organic matter; and low soil depth
- Slope: mostly flat (0-2%) in oasis
- Landform: mainly mountains, valley floors
- Altitude: 800 m a.s.l.

Socio-economic conditions

- Size of land per household: <1 ha
- Type of land users: individuals / families; mainly poor land users
- Population density: 10,000 persons/km^2 (oasis)
- Land ownership: mostly individual, untitled
- Land use rights: individual, communal (unorganised)
- Market orientation: mostly subsistence (self-supply), partly mixed (subsistence and commercial)
- The land user can be (1) the owner of the garden; (2) a family member managing the family-owned garden; (3) a paid labourer; (4) a usufructuary

Production / economic benefits

+++ Increased crop yield, fodder and animal production
+++ Increased fodder quality and animal diversity
+++ Increased farm income

Ecological benefits

+++ Improved soil cover
+++ Reduced wind velocity and soil loss
+++ Increased soil fertility
(+++Increased biomass / above ground carbon)
++ Reduced fire risk

Socio-cultural benefits

+++ Conflict mitigation
+++ Community institution strengthening through mutual aid in technology implementation
+++ Improved cultural opportunities
+++ Improved food security

Off-site benefits

++ Reduced damage on public / private infrastructure
+++ Reduced wind transported sediments

Weaknesses ➜ and how to overcome

- High implementation costs ➜ establish national financial support systems for acquisition of garden area by very poor people.
- High maintenance costs ➜ promote efficient irrigation technologies that reduce maintenance costs (such as drip irrigation).
- Uncontrolled spread of the technology resulting in an overexploitation of groundwater and over-production of e.g. onions ➜ increase water use efficiency; regulate market and promote agro-industrial food processing.
- High dependency on climatic factors influencing the recharge of the groundwater level ➜ exploitation of deep water resources through artesian wells and introduction of adapted drip irrigation technologies.

Adoption

The gardens are traditional with a high trend of spontaneous adoption. The technology was an answer to the successive droughts in the 1970ies and 1980ies which have caused heavy livestock losses in the region. Pastoralists adopted the technology to diversify their livelihoods and minimise risk. Since the 1990ies, 700 new irrigated gardens were established in Timia (as compared to 100 gardens).

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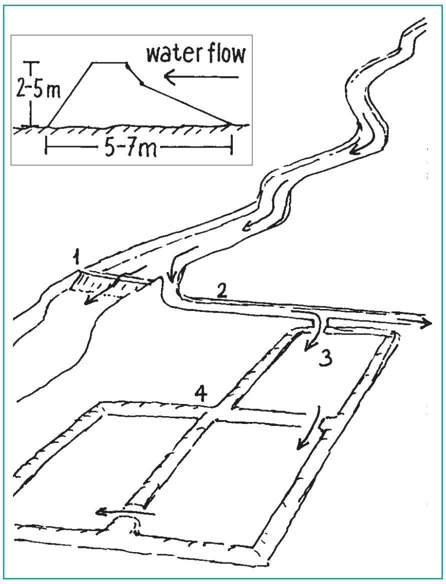
SPATE IRRIGATION - ERITREA

Spate irrigation has a long history in Eritrea and still forms the livelihood base for rural communities in arid lowlands of the country. It is a traditional water diversion and spreading technique under which seasonal floods of short duration – springing from the rainfall-rich highlands – are diverted from ephemeral rivers (wadis) to irrigate cascades of leveled and bunded fields in the coastal plains. The diversion structures include the following elements: (1) the '*agim*', a temporary 3-4 m high river diversion structure on the low-flow side of the wadi, made from brushwood, tree trunks, earth, stones and / or boulders, erected to divert a large part of the flow during a spate flow to adjacent agricultural fields; (2) a primary, and several secondary distribution canals; unlined, bordered by earthen embankments; convey and spread the floodwater to the irrigable fields; (3) the fields, rectangular shaped, of about 1–2 ha, separated by earthen bunds. Floodwater is distributed from field to field: when a field is completely flooded (to a depth of about 0.5 m), water is conveyed to the immediate downstream field by breaching one of the bunds. This process continues until all the water is used up. Arable fields need to be flooded several times.
The water soaks deep into the soil profile (up to 2.4 m) and provides moisture sufficient for two or even three harvests: crop growth is entirely dependent on the residual soil moisture. The main crop grown is sorghum; maize is the next most important. Sedimentation is as important as water management: With each flood, soil is built up by depositing rich sediment on the fields. Due to the force of the floods, the diversion structures are frequently damaged and / or washed away. Reconstruction and maintenance are labour-intensive and require collective community action. Elaborate local regulations, organisation and cooperation at the community level are prerequisites for successful management of spate irrigation systems.



SLM measure	Structural
SLM group	Smallholder Irrigation Management
Land use type	Annual cropping
Degradation addressed	na
Stage of intervention	na
Tolerance to climate change	Tolerant to climatic extremes (adapted to unpredictable heavy floods)

Establishment activities

1. Construction of diversion structure (*agim*).
2. Construction of main distribution canal.
3. Construction of secondary distribution canals.
4. Leveling of fields.
5. Establish embankments around fields and within fields.

All activities are carried out by manual labour and animal traction, before the highland rainy season.

Maintenance / recurrent activities

1. Reconstruction / repair of diversion structures (2-4 times/year; collective community action).
2. Annual desilting / repair of distribution canals.
3. Annual raising of bund heights due to silting up of fields.
4. Flood fields (community action, during highland rainy season: July-September). Most likely a field receives 3 irrigation turns, on a bi-weekly interval between any 2 turns.
5. Soil tillage (15 cm deep; using oxen-drawn plough) to break capillary uplift of soil water and to create evaporation barrier (end of the flooding season).
6. Sowing (10 days after last flooding; Mid September).

Labour requirements

For establishment: high
For maintenance: high

Knowledge requirements

For advisors: high
For land users: high

Photo 1: Social organisation and community action are prerequisites for spate irrigation systems: construction of an *agim* in a dry river bed. (IFAD)
Photo 2: Fertile sediments and spate irrigation result in high sorghum yields. (IFAD)
Technical drawing: Cross section of an agim (top left); Components of a traditional spate irrigation system: (1) agim; (2) main distribution canal; (3) irrigated fields; (4) earthen embankments. Arrows indicate the water flow. (Mats Gurtner)

Case study area: Wadi Laba, Sheeb area, Eastern lowlands, Eritrea

Establishment inputs and costs per unit

Inputs	Costs (US$)
Labour: 12 person-days	no data
Equipment / tools: 4 camel-days, 10 pairs-of-ox-days, scouring and tillage implements, shovels	no data
Agricultural inputs: none	no data
Construction material: tree trunks, brushwood, stones, boulders, earth	no data
TOTAL	**60**
% of costs borne by land users	100%

Maintenance inputs and costs per unit* and year

Inputs	Costs (US$)
Labour	no data
Equipment: camels, oxen, scouring and tillage implements	no data
Agricultural inputs: none	no data
Construction material: tree trunks, brushwood, stones, boulders, earth	no data
TOTAL	**48-96**
% of costs borne by land users	100%

* unit = 10 m long *agim* (1 m high, 3 m wide), constructed with mixed material (stones, earth, brushwood)

Remarks: Data on labour inputs for construction / maintenance of canals and field bunds are not included, therefore not included in the tables above. Costs for *agim* reconstruction are 40% of establishment. Total maintenance costs depend on the number of reconstructions during normal spate season (2-4 times). The yearly cost (establishment and maintenance) reaches US$ 60-156.

Benefit-cost ratio

Inputs	short term	long term
Establishment	no data	no data
Maintenance	no data	no data

Ecological conditions

- Climate: arid (hot, high evapotranspiration)
- Average annual rainfall: < 200 mm
- Soil parameters: very deep and fertile soil (alluvial silts), formed by annual sedimentation; well drained, soil texture: loams to silt loams
- Slope: flat (0-2%)
- Landform: plains (alluvial plains of the coastal area)
- Altitude: 200 m a.s.l.
- The alluvial plains are cut through by wadis discharging into the Red Sea. The spates account for 65% of the annual flow volume. 75% of the irrigated land in Sheeb is watered by the main wadi. Floodwater is unpredictable in timing and volume, and has high destructive potential.

Socio-economic conditions

- Size of land per household: no data
- Type of land user: small-scale, poor to very poor land users; water management carried out communally, crop management individually
- Population density: low
- Land ownership: state
- Land use rights: individual
- Level of mechanisation: manual labour and animal traction

Production / economic benefits

+++ Increased crop yield
+++ Increased fodder production (residues are fed to livestock)
+++ Increased production area (without irrigation, agricultural production is not possible)
+++ Increased water availability
+++ Increased farm income

Ecological benefits

+++ Improved harvesting / collection of water
+++ Increased soil moisture
+++ Increased soil fertility

Socio-cultural benefits

+++ Improved food security
+++ High level of cooperation and organisation on community level

Weaknesses ➜ and how to overcome

- Highly labour-intensive and time consuming maintenance; water diversion structures are frequently breached / washed away by heavy floods; canals are obstructed through deposition of boulders, gravel and coarse sediments ➜ yearly repair / reconstruction is required.
- Great demand for wood: huge numbers of trees are annually needed for (re-) constructing diversion structures.
- Irrigation efficiency is only about 20% because of the difficulty of controlling large amounts of water in a short period of time (and often at night) and because water is lost by percolation, seepage and evaporation ➜ to overcome all 3 problems, recommendations focus on building permanent flood diversion and distribution structures which: (1) withstand the force of heavy floods and divert the water effectively; (2) eliminate the need to cut trees; (3) reduce human and animal labour inputs; (4) increase productivity. Lining the main canals with cements would reduce water loss by percolation and seepage. Proper leveling of basin fields helps to distribute the floodwater uniformly.

Adoption

Spate irrigation is an indigenous technology, originally introduced from Yemen. Spontaneous spread takes place throughout the lowlands. Current spate irrigation area in Eritrea is 16,000 ha. Potential area is estimated at 60,000–90,000 ha.

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