WAHARA - Report Series

INTEGRATIVE ANALYSIS OF RESULTS FROM THE FOUR COUNTRIES

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Integrative analysis of results from the four countries
WAHARA WP 5, deliverable 1

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1. Introduction

This report reviews different water harvesting (WH) applications regarding their impact on rainfed agriculture in Africa. It brings together knowledge about indicators for adoption of WH technologies. It precedes two other reports under WAHARA work package 5, viz. deliverable 2, which goes in depth into how to increase the scope for outscaling of WH technologies through adaptation, and deliverable 3, in which practical WH adaptation guidelines are worked out.

The information used in this report is from the WAHARA work packages 1-4 and the study sites as well as other WH experience, including knowledge such as provided in WAHARA reports 5-9 and 16 (Ouessar, Hessel, Sghaier, & Ritsema, 2012; Glotzbach, et al., 2011; Bardin, 2012; Sawadogo H., 2011; Sawadogo & Janvier, 2012; and Sawadogo, Yazew, Chomba, & Ouessar, 2013 respectively).

2. Overview of results from WAHARA work packages 1-4

Description of WH technologies

WAHARA focused on WH technologies which are:

- Low-cost interventions
- Intended to conserve and/or control natural water resources, notably rainfall, run-off, flooding
- Buffering water through storage and recharge on or below the surface of the land
- Enabling water use that can be for multiple purposes, e.g. for crop growing, livestock production and farm household water needs
- Either implemented as independent units or embedded in a larger system

These WH technologies can fall in any of the WOCAT[1] categories of land and water conservation measures (WOCAT-Categorisation System):

- *Agronomic*: maintaining soil cover (e.g. cover crops, mulch), improving soil fertility (e.g. inorganic fertilisers, lime, compost) and/or optimising soil tillage (e.g. ripping, zero-till, ridging)
- *Vegetative*: planting and/or maintaining perennial -herbaceous as well as woody- vegetation (e.g. trees, pasture) and controlling it (e.g. burning of excess woody material)
- *Structural*: building and maintaining permanent physical structures using soil and/or other materials such as stones, wood and cement (e.g. sloping or level terraces, banks, drains, pits, dams, land rehabilitation)
- *Management*: optimising land use type or operations, including their lay-out, timing and control of natural vegetation (e.g. changing from grazing to cropping, from free communal grazing to controlled grazing, from staple to high value cropping, from hand hoe to animal traction mechanisation, from hoe weeding to using cover crops or herbicides, and applying selective clearing of bush encroachment).

A description of the four WAHARA study sites and their WH potentials is given in WAHARA reports 3, 4, 10, 24, 25 and 26 (Ouessar, Sghaier, Zaied, & Abdeladhim, 2015; Ouessar, Hessel, Sghaier, & Ritsema, 2013; Ouessar, Hessel, Kirkby, Sghaier, & Ritsema, 2013; Kaushali & Fleskens, 2015; Arbi, Sghaier, & Ouessar, 2015; Nega & Woldearegay, 2015 respectively). Below is an overview of the 16 WH technologies studied at the WAHARA study sites. Some of these and other WH technologies and two WH approaches were described for inclusion in the WOCAT database[2]; see Table 1.

[1] https://www.wocat.net/
[2] https://www.wocat.net/en/knowledge-base.html

Table 1. WH technologies and approaches described by WAHARA for the WOCAT database

Reference	***WH technology/approach***	***Country***
T_BRK012	Bassin de captage des eaux de ruissellement (Banka)	Burkina Faso
T_BRK013	Bouli	Burkina Faso
T_BRK014	Ados	Burkina Faso
T_BRK015	Zaï forestier	Burkina Faso
T_BRK016	Tapis herbacé	Burkina Faso
T_ETH605	Soil faced deep trench bunds	Ethiopia
T_ETH606	Large semi-circular stone bunds	Ethiopia
T_ETH607	Check dam ponds	Ethiopia
T_ZAM002	Strip tillage conservation farming	Zambia
T_ZAM003	Conservation tillage with Magoye Ripper	Zambia
T_ZAM004	Animal draft zero-tillage	Zambia
A_ZAM001	Participatory research and development	Zambia
T_TUN009	Jessour	Tunisia
T_TUN010	Gabion check dam	Tunisia
T_TUN012	Tabia	Tunisia
T_TUN013	Cistern	Tunisia
T_TUN014	Recharge well	Tunisia
A_TUN009	Dryland watershed management approach	Tunisia

Source: WAHARA report 18 (Sawadogo, et al., 2013)

Burkina Faso

1. *Stone bunds*. Rows of stones along the contour to reduce erosion

2. *Zaï*. Hand dug planting basins that catch run off


3. *Magoye ripper*. This technology from Zambia was introduced as a possible solution to the request from farmers to mechanise the manual zaï system. After the first tests which were successful, the design was improved and adapted to suit the working conditions in Burkina Faso better (Figure 4).

4. *Bouli*. A traditional WHT for many uses in the dry season: water to drink for humans and cattle, to build houses and to wash clothes. It consists of digging a big hole: 30-40m of diameter with a depth of 6m or more. Nowadays, the bouli has been improved by Projects, NGO and research for irrigated crops in the dry season and wet season (rice).The bouli can retain water for 4-7 months

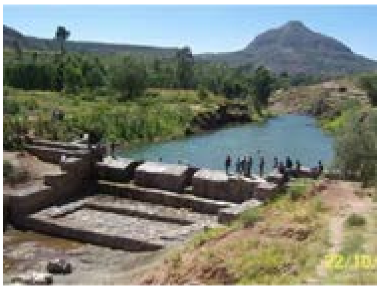
with a depth of 10 m. The bouli is an important socio-economic tool for the rural population in the context of climate change

5. *The Banka or Stock Water Basin*. The Banka is a traditional WHT for human and animal drink in the rainy season. Nowadays, the Banka has been improved for supplemental irrigation by projects, NGOs and research work. The Banka is a rectangular hole with length of 12 m, width of 8 m, and depth of 2 m. The capacity of the Banka is estimated to be 150,000 litres. The Banka can retain water for 30-40 days. The Banka allows mitigation of the effects of short-term droughts. The benefits are not yet well established by researchers since the use of this technology is in its first step.


Ethiopia

1. *Percolation pond*. These technologies can be applicable at hill bottoms if the soil is characterized by high infiltration rates. Good results with this technique were observed in many areas of Tigray. Percolation ponds can encourage infiltration and subsequent recharge of the groundwater and enable the construction of hand dug wells in the valley bottoms due to increased ground water level.

2. *Check dam pond.* A check dam is a raised wall constructed across a gully from stone, concrete or gabion to store water behind it for irrigation purpose using either gravity or a lifting mechanism. The structure generally consists of construction of foundation, apron, retaining wall and the check dam itself. The width of the check dam ranges between 1-2 m while the height varies between 1-2 m depending up on the gully depth. The length of the check dam depends on the gully width while the spacing between adjacent check dams is determined based on the availability of water and a potential land that can be irrigated. Check dams are also provided with a number of sluice gates which will be removed during the main rainy season to minimize siltation



3. *Bench terraces.* The purpose of bench terraces is creation of new cultivable land on hill sides. During the stakeholder WH technology selection workshop held in WP2, the workshop participants chose bench terrace with hillside cisterns as top priority of interventions

4. *Soil improvement*. Implementation of different soil management techniques such as the application on the crop land of mulch, compost and Effective Micro-organisms (EM) can improve the fertility and productivity of the land as well as increase infiltration rate and water storage capacity of the soil .


Tunisia

1. *Jessour*. Made of three components; the impluvium, the terrace and the dyke. Each unit has its own impluvium, but can also receive excess water from upstream units. Farming is practised on the terrace; which is formed progressively by the deposition of sediment behind a dyke

2. *Tabia*. Like jessour, comprised of a dyke, a spillway and an impluvium. The differences between the tabia and the jessour systems are that the former contains two additional lateral bunds (up to 30 m long) and sometimes a small flood diversion dyke. Tabia are more applied in the foothills whereas jessour are found more in the mountains

3. *Gabion check dam*. In order to slow down the water flow in the wadi courses and improve its infiltration into deeper soil layers and geologic formations, check dams are installed on the wadi beds



4. *Cistern*. Reservoir used for storing rainfall and runoff water for multiple purposes: drinking, animal watering and supplemental irrigation

5. *Recharge well*. Made of casting tube, drilled up to 30-40 m to reach the water table, and a filter used to allow the direct injection of floodwater into the aquifer. Recharge wells are installed in


reservoirs that are created by the check dams. They increase infiltration rates into the aquifer when the reservoir is filled with water; which is only the case after heavy rain

6. *Zaï*. To optimise the productivity of the water harvested by jessour and tabia, this technology from Burkina Faso was introduced for testing as well.

Zambia

1. *Magoye ripper*. An animal drawn implement used for conservation tillage to break up soil without inverting it. Planting is done in the furrow produced by the tool.

2. *Zero tillage*. Animal draft zero-till planter to plant directly in untilled soil.

3. *Strip tillage conservation farming*. An animal drawn reduced tillage method that involves loosening a strip of soil where the crop will be planted with a strip tillage tool.

Table 2 gives an overview of some key characteristics of the above WH technologies.

The technologies were chosen by the stakeholders based on their current or expected importance for the area according to prior agreed criteria and priorities. The procedures of this participatory selection approach are explained in WAHARA report 17 (Sawadogo, Hessel, & Ouessar, 2013) and the results presented in report 18 (Sawadogo, et al., 2013) as well as specifically for Tunisia also in WAHARA report 14 (Arbi, Ouessar, & Sghaier, 2013) and for Ethiopia in MU WAHARA team (2013) and WAHARA report 15 (WAHARA Research Team of Mekelle University, 2013). The stakeholders agreed on the criteria and their relative importance (Table 3).

Improved crop yields were higher ranked than improved income, which may reflect a priority for food security rather than monetary income. Remarkably, together with improved crop yields, environmental criteria (biodiversity, reduced soil erosion) appear among the top priorities. Possibly this recognizes the stakeholders' awareness of their great dependency on natural resources.

Table 2. Comparison of key characteristics for the WH technologies at the study sites

Water harvesting technology	WOCAT reference	Study Site	Water catchment	Water buffering	Main purpose(s)	Application level		Basic water harvesting principles involved			The crop's access to the harvested water
						Locational level	Management level	Place(s) of water collection	Water transport principle(s)	Place(s) of water storage	
Stone bunds		Burkina Faso	Micro	Root zone	In-situ soil and water conservation for crop production Reduced run-off Management of run-on	Field	Individual farmer	Field (in-situ) Up-slope surface outside field (run-on)	Surface micro flows Infiltration Percolation	Root zone, of entire field Some below root zone Some on surface (puddles along bunds)	Soil moisture in root zone
Zaï		Burkina Faso	Micro	Root zone	Soil and water conservation for crop production Reduced run-off	Field	Individual farmer	Field (in-situ) Up-slope surface outside field (run-on)	Surface micro flows Infiltration Percolation	Root zone, especially near planting pits Some below root zone Some on surface (puddles in pits)	Soil moisture in root zone
Magoye ripper		Burkina Faso	Micro	Root zone	Soil and water conservation for crop production Reduced run-off	Field	Individual farmer	Field (in-situ) Up-slope surface outside field (run-on)	Surface micro flows Infiltration Percolation	Root zone, especially near planting furrows Some below root zone Some on surface (puddles in furrows)	Soil moisture in root zone
Banka		Burkina Faso	Macro	Open surface	Water catchment and storage for irrigation and other uses: livestock drinking, people bathing and washing	Farm	Individual farmer	Up-slope surface	Run-off from up-slope Percolation	Pond Surrounding soil (below root zone)	Irrigation: water lifted from open water surface
Bouli	T_BRK013	Burkina Faso	Macro	Open surface	Water catchment and storage for irrigation and other uses: livestock drinking, people bathing and washing	Landscape	Group of farmers, Local community	Up-slope surface	Run-off from up-slope Percolation	Pond Surrounding soil (in and below root zone)	Irrigation: water lifted from open water surface

Table 2. Comparison of key characteristics for the WH technologies at the study sites (continued)

Water harvesting technology	Wocat reference	Study site	Water catchment	Water buffering	Main purpose(s)	Application level		Basic water harvesting principles involved			The crop's access to the harvested water
						Locational level	Management level	Place(s) of water collection	Water transport principle(s)	Place(s) of water storage	
Percolation pond		Ethiopia	Macro	Ground water	Groundwater recharge, flood control	Field or farm	Individual farmer, group of farmers, government etc.	Up-slope surface runoff	Run-off, infiltration, percolation	Pond and wells, surrounding soil, water table	Soil moisture, increased water table, irrigation
Check dams		Ethiopia	Macro	Open surface	Sediment storage, groundwater recharge	Landscape	Individual farmer, group of farmers, government etc.	Stream with barrier	Water flow in stream bed, infiltration, percolation	Pond in stream bed, surrounding soil, water table, aquifer	Soil moisture, increased water table, irrigation
Bench terraces		Ethiopia	Macro	Ground water	Create cultivable land, reduce erosion	Landscape	Government, local community	Up-slope soil surface, micro-catchments and barriers	Run-off , drainage and infiltration	Soil	Increased water table, soil moisture and irrigation
Soil improvement		Ethiopia	Micro	Root zone	Enhance soil moisture and productivity	Field	Individual farmer	In-field micro-catchment (by well-structured soil)	Infiltration	Soil	Soil moisture
Tabia	T_tun012	Tunisia	Macro	Root zone	Agriculture	Farm	Individual farmer	Slopes	Runoff water courses	Soil	Root zone
Jessour	T_tun009	Tunisia	Macro	Root zone	Agriculture	Farm	Individual farmer	Slopes	Runoff water courses	Soil	Root zone
Recharge wells	T_tun014	Tunisia	Macro	Ground water	Groundwater recharge	Catchment	Government	Wadi beds	Runoff water courses	Aquifer	Irrigation
Zaï		Tunisia	Micro	Root zone	Agriculture	Farm	Individual farmer	Farm	Direct	Soil	Root zone
Gabion check dam	T_tun010	Tunisia	Flood	Ground water	Groundwater recharge	Catchment	Government	Wadi beds	Runoff water courses	Aquifer	Irrigation
Cistern	T_tun013	Tunisia	Micro	Closed tank	Water harvesting	Catchment	Individual farmer	Slopes	Runoff water courses	Tank	Irrigation
Zero-till planter	T_zam004	Zambia	Micro	Root zone	Soil and water conservation for crop production	Field	Individual farmer	In-field micro-catchment	Infiltration	In-field soil profile	Soil moisture
Strip tillage	T_zam002	Zambia	Micro	Root zone	Soil and water conservation for crop production	Field	Individual farmer	In-field micro-catchment	Infiltration	In-field soil profile	Soil moisture
Magoye ripper	T_zam003	Zambia	Micro	Root zone	Soil and water conservation for crop production	Field	Individual farmer	In-field micro-catchment	Infiltration	In-field soil profile	Soil moisture

Table 3. WH technology evaluation criteria as agreed by the stakeholders at each study site

Criteria rank	Burkina Faso	Ethiopia	Tunisia[a]	Tunisia[b]	Zambia
1	Improve yield	Improve productivity	Conserving water & soil	Increasing crop yields	*Not clear*
2	Increase biodiversity	Protect against erosion, increase arable land and reclaim plantation	Conserving biodiversity	Increasing farm income	
3	Give income	Adaptable and socially acceptable	Groundwater recharge	Construction and maintenance costs	
4	Crop diversification	Profitable	Increasing crop yields		
5	Improve water availability	Beneficial to females and youth	Increasing farm income		
6		Adaptable to different ecological conditions	Unemployment reduction		

[a] Based on environmental, economic and social criteria; [b] Economic criteria only
Source: Kaushali & Fleskens, 2015

In Table 4 the 16 WH technologies evaluated at the WAHARA study sites are arranged according to implementation level and the way the crop has access to the harvested water; either the water becomes directly available to the crop as it is stored in the soil or at a later stage through irrigation by people). Some of the latter type hold water in natural or dug out ponds that may wet the surrounding soil temporarily hence enabling a rainfed crop (but which usually needs supplementary irrigation from the nearby pond as well). In Ethiopia, the bench terraces' main purpose is to create new agricultural land. The terraces catch and hold rain and run-off water which is used for crops on the terraces hence are rainfed, but require additional irrigation measures such as from cisterns. Although usually implemented at landscape/catchment level, bench terraces and cisterns are meant for use by individual farmers. Percolation ponds in Ethiopia are implemented at field/farm level by individual farmers but also in groups and with government support. Check dams are used in Ethiopia and in Tunisia for different main purposes; in Ethiopia for irrigation (check dam ponds) or for rehabilitating degraded gullies and also for groundwater recharge (gabion check dams) and in Tunisia for recharge of the groundwater.

Table 4. The WH technologies according to implementation level and the crop's access to water

Farm/Field		Landscape/Catchment	
Access to water by the crop		***Access to water by the crop***	
Direct	***Through irrigation***	***Direct***	***Through irrigation***
Stone bunds	Banka	Bench terraces	Bouli
Zaï	Percolation pond		Check dams
Soil Improvement			Recharge wells
Tabia			Gabion check dam
Jessour			Cistern
Zero-till planter			
Strip tillage			
Magoye ripper			

The two flood irrigation systems, tabia and jessour, are listed as direct as in these systems water is actually not stored for irrigation and at a later stage brought artificially to the crops as is done in the other 'real' irrigation systems. Instead they direct water immediately to the crop, more or less as done for instance with bunds, half-moons, ridges and furrows, only at a much larger scale.

The WH systems with *direct* access to the water by the crop are all managed by individual farmers and in all the study sites such systems are being used by individuals. The irrigation systems are mostly for a larger level of implementation and required in more arid regions. They require additional in-situ systems such as zaï and soil improvement measures to ensure a productive use of the precious water. This is also the case for tabia and jessour but in fact for all systems it is important to combine measures for optimal water productivity (i.e. the amount of crop production per unit of water).

The following information from the study sites was reported in WAHARA reports 28-30 (Woldearegay, et al., 2015a, Ouessar, Sghaier, Zaied, & Abdeladhim, 2015, Woldearegay, et al., 2015b):

Burkina Faso

- The adapted Magoye ripper from Zambia is a solution to the request by farmers to mechanise the popular zaï system, which is based on manual labour
- Use of soil fertility improving measures (compost and micro-dosing of fertilizer) made zaï more effective
- The combination of the use of improved seed varieties, soil management and supplementary irrigation from run-off water collected in dug ponds (banka) proved most gainful
- Access to seed of the right crop types and varieties is important (as demonstrated by the improved cowpea varieties tests in combination with zaï and appreciated by the women involved).

Ethiopia

- Pulling together the resources of different organisations (logistics, finances, expertise) enabled to realize the costly and involving WH works needed to create percolation ponds, check dams and bench terraces. The same cooperation is likely to facilitate further outscaling of WH. It also facilitates the uptake of research results as development organisations like to work and learn from researchers. However, there is still lack of knowledge how best to link research and development. The stakeholder workshops for information sharing and selecting WH technologies played a useful role in this regard; researchers not only could mobilize the all-important participation of the locals, but also received extremely relevant knowledge from them
- The design specifications of bench terraces, check dams and percolation ponds were adapted based on feedback from the field
- A combination of WH technologies (trenches, bench terraces, check-dams, afforestation) is most effective to harvest water in an entire watershed
- Bench terraces are a way to create new agricultural land in places where this is scarce, and is important for employment of notably the youth. However, the costs involved for constructing the terraces requires them to become highly productive. Hence the need for productive farm inputs and high-value crops grown intensively (fruit trees and vegetables allowing for multi-level cultivation) as well as a guaranteed water supply. Although the terraces reduce run-off and are instrumental in ground water recharge, the cropping system required supplement moisture, which was realised with water tanks (cisterns)
- Check dams reduce gully erosion, enhance groundwater recharge, store sediments and buffer moisture and enhance water availability at landscape level. In this way they are important for creating multiples ecosystem services and opening up different agricultural, employment and investment opportunities for communities, so are in themselves an important adaptation to people’s livelihoods in their own right
- Ground water recharge through gabion check dams rendered shallow wells productive and made digging new ones worthwhile
- Supporting farmers to improve and maintain a productive soil health was proven important and requiring more attention. Organic ways of soil health improvement (mulching and dosing of effective micro-organisms and the use of vermiculite) are envisaged for further study

- Ex-situ WH facilities need to be strategically placed near agricultural land where the harvested water can be utilised well, as otherwise they will be less practical.

Tunisia

- Jessour and tabia are not sufficient during prolonged drought; additional in-situ WH systems that optimise the use of the scarce water for the crop, such as zaï, may in some years help to prevent total crop loss
- Zaï are a useful addition within jessour and tabia for the establishment of trees
- Groundwater recharge wells tend to silt up, so there is need to install siltation traps
- There is a risk of industrial and agricultural pollution of groundwater through the open connection with the surface through the recharge wells. This potential situation must be monitored and prevented wherever necessary.
- Van den Bosch, Hessel, Ouessar, Zerrim, & Ritsema (2014) observed in WAHARA report 22 from research on the saturated vertical hydraulic conductivity of retention basins in Tunisia that results of their work did not lead to the conclusion that a significant amount of water is lost to evaporation due to the stagnation of water. In a retention basin with average hydraulic conductivity, only 0.5% of the water is lost to open water evaporation, although lower layers might cause a stagnation of the water, thereby increasing the amount of water lost to evapotranspiration.

Zambia

- Similar to the zaï in Burkina Faso, also in Zambia it is important to solve labour requirement issues experienced with the manually conservation farming system. All oxen-based systems tested under WAHARA are an effective answer to that, provided there is an efficient weeds control system in place
- Farmers would welcome dams (e.g. for irrigation and livestock production).

Overall, combinations of WH technologies proved to be important in different ways:

- Different WH technologies in different places in the watershed to complement each other and optimise water harvesting (as demonstrated in Ethiopia)
- A high variety of useful mixes of in-situ rainwater harvesting measures, micro-catchment systems and/or macro-catchment systems
- WH in combination with land management (e.g. create land on steep slopes by bench terraces and gully rehabilitation by gabion check dams)
- WH and irrigation, either irrigation to complement WH (e.g. supplementary irrigation under extreme dry conditions) or WH opening the opportunity to irrigate (e.g. check dam ponds)
- Soil improvement measures are important to make soil a better water bank (a WH technology in its own right) as well as to make other WH technologies if combined (more) worthwhile through improved productivity
- WH technologies embedded in a more market-oriented production system, not only to complement other productive farming resources but also this farming approach often being a necessity for the WH technology to be worthwhile (farming for business making WH feasible).

Furthermore, in a choice experiment, the productivity and risk reduction as perceived by the stakeholders were compared. Results are presented in WAHARA report 24 (Kaushali & Fleskens, 2015). The authors concluded that *risk reduction* seemed to be more prominent at the more arid sites of Ethiopia and Tunisia, and mostly so in Tunisia, whereas at the two other sites (Burkina Faso and Zambia), which are in more sub-humid environments, *yield increase* was higher valued.

Quick Scan

In an Africa-wide quick survey the WH potential across the continent was mapped (Figure 1- left). The WH potential was assumed being the simple ratio of rainfall to potential evapotranspiration during the cropping season. In areas with a ratio below 0.2, water harvesting would not be possible or relevant because it would simply be too dry there. Areas with a ratio above 1.5 would not need water harvesting as they are wet enough. This leaves large regions with obvious WH potential (ratio between 0.2 and 1.5) in most of Eastern and Southern Africa as well as in bands north and south of the Sahara. The rather crude method does not take into consideration WH potential in areas with a ratio above 1.5 where crops can overcome seasonal dry spells with the help of WH technologies that improve the water storage in the soil or cater for supplementary irrigation. These more humid zones are potentially important WH target areas as they are in regions with high population density (Figure 1) and markets that make investments in WH both necessary and affordable. Figure 1 also shows the location of the 4 study countries in WAHARA. The exact positions of the study sites are not indicated, but the sites are located respectively in Southern Tunisia, Northern Ethiopia, Northern Burkina Faso and Southern Zambia. Figure 1 shows that for these locations, the ratio between rainfall and evapotranspiration varies between about 0.5 and 1.5.

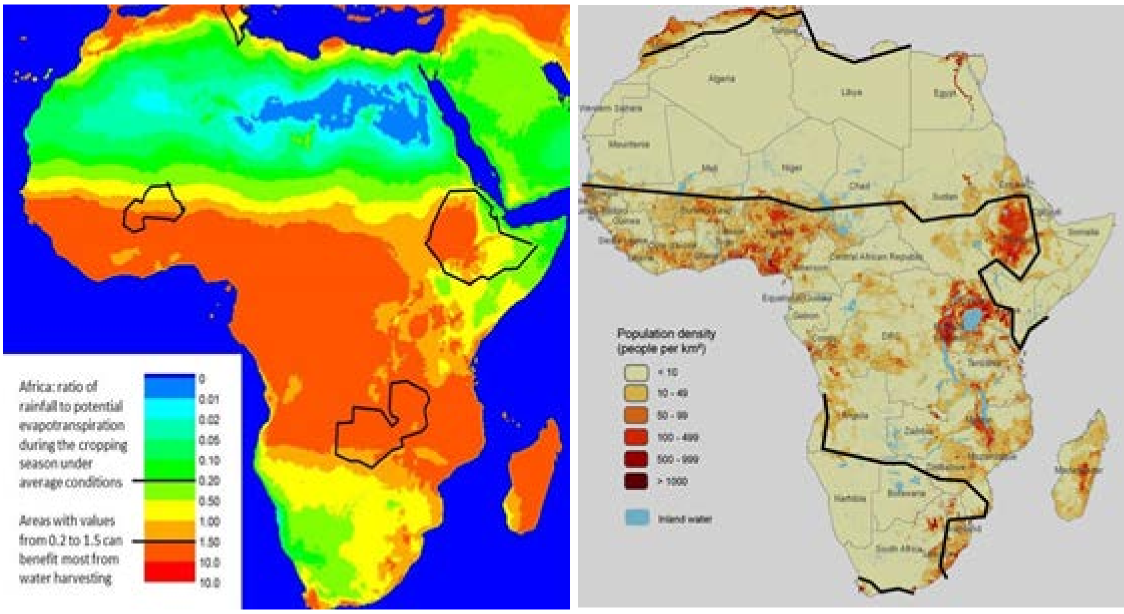


Figure 1. WAHARA's Africa-wide quick survey shows where WH would have highest potential.
Source: Fleskens, Irvine, & Kirkby, 2012 (WAHARA Power Point presentation)

WAHARA report 19 (Kirkby & Irvine, 2013) presents an at-a-point *Quick Scan* tool in Excel designed to assess the WH potential for a specific site. It estimates the rainfall deficits in a given location (spatial resolution about 15 km^2) and accordingly produces the preferred ratio of water harvesting area to cropped area (CAR) for that location. The tool is able to forecast crop yields and risks of water deficits for different CARs over a period of 50 years for variable climate change scenarios. Knowledge about the preferred CAR gives hints for possibly suitable WH approaches for that location.

PESERA/DESMICE

WAHARA report 23 (Fleskens, Irvine, & Kirkby, 2015) introduces and describes an integrated *PESERA/DESMICE* model capable of simulating hydrological and economic impacts, including food and water security, of WH from field to regional scale. The model was developed to assess the impact of the WH technologies using the experimental data from the study sites. Results give insight in the scope of application of the technologies beyond the study sites.

A WH decision support approach

Using data from the study site in Ethiopia, Grum, et al. (under review) developed a practical approach to identify areas that are potentially suitable for particular WH technologies (based on just 5 biophysical criteria - Table 5). The technologies were selected by experts and stakeholders from a database of WH technologies (Table 6). The approaches, and associated table, are applicable throughout Africa, while the approach was tested for the upper Geba Watershed in Tigray, Ethiopia. For this watershed, digital maps were created for slope, texture, land-use/cover and stream order. The maps were then checked against the corresponding set of suitability criteria for the selected WH technologies to produce biophysical suitability maps. When validating the maps, it was found that 90% of the existing check dams and 93% of the existing percolation ponds were located in areas that were mapped as being highly or moderately suitable area for that technology (Figure 2).

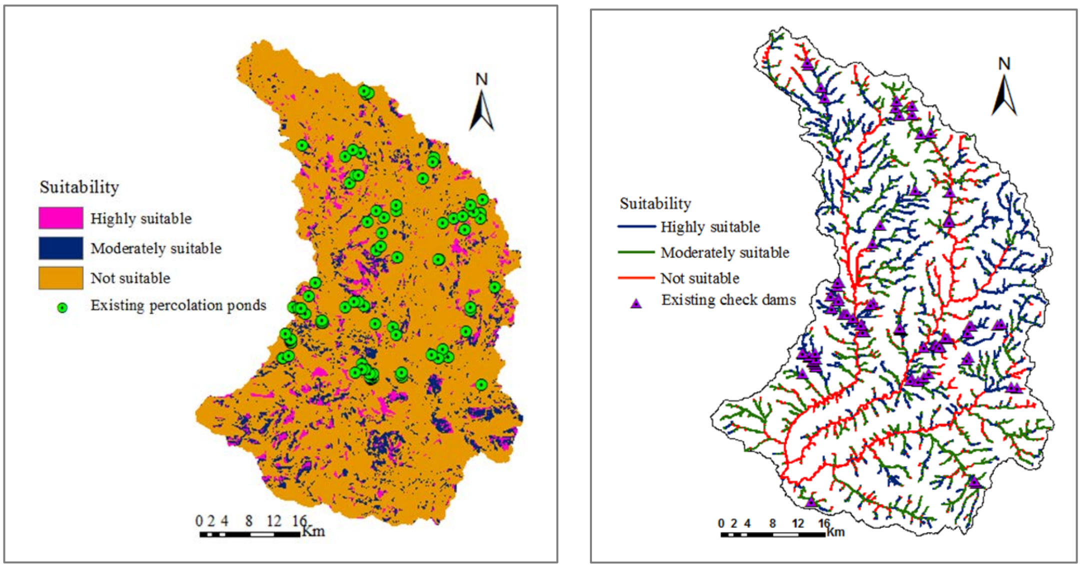


Figure 2. Biophysical suitability maps for WH technologies
in the upper Geba watershed (Ethiopia) for percolation ponds (left) and check dams (right)
Source: Grum et. al., under review

In the light of Africa-wide WH outscaling, the approach provides a useful tool for assessing the potential scope of a particular WH technology for any area, as well as for narrowing down the area for which the technology should be considered. The maps are a good visual aid in participatory WH technology information and selection meetings, in which socio-economic aspects are yet to be taken into account as well.

Table 5. Suitability criteria of the WH decision support approach developed in Ethiopia

Water harvesting techniques	***Slope (%)***	***Soil properties***	***Land use/cover***	***Annual rainfall depth (mm)***	***Stream order***
Check dams	≤15	Fine loam	River streams ≤ 700 m from cultivated land	250-750	1st to 3rd
Percolation ponds	≤10	(Sandy) clay loam with moderately high infiltration rate	Bare/shrub land, grass land, along stream beds	250-750	2nd and 3rd
Bench terraces	20-60	All agricultural soils except shallow ones	Bare/shrub land, cultivated land	200-600	Not applicable

Source: Grum et al., under review

Table 6. Database of technologies for the WH decision support approach

Water harvesting techniques	**Suitability indicators**						
	Slope (%)	***Land use***	***Soil properties***	***Annual rainfall (mm)***	***Topography***	***C:CA ratio***	***Limitations***
In-situ rainwater harvesting							
Mulching	0-5	Cultivated land	Impermeable soil	200-800	Low topographic relief	Not applicable	Not suitable in areas with high rainfall
Conservation tillage	0-5	Cultivated land	Impermeable soils	200-800	Low topographic relief	Not applicable	Problem of compaction, flooding or poor drainage
Micro-catchment systems							
Negarim micro-catchments	1-5	Cultivated land, bare/shrub land	Thick soils (at least 1.5 metre deep)	100-400	Even and uneven micro- catchments	1:1-25:1	Cannot be mechanized
Meskat systems	2-15	Cultivated land	All agricultural soils	200-400	Even and uneven micro- catchments	2:1	Lack of uniformity in water distribution in the cropping area
Contour bench terraces	20-60	Bare/shrub land, cultivated land	All agricultural soils except shallow ones	200-600	Even and uneven micro- catchments	1:10	High construction and maintenance costs, cannot be mechanized
Semi-circular bunds/half-moons/triangular bunds	0.5-5	Bare/shrub land, cultivated land	All soils not shallow and saline	200-750	Even topography	3:1	Cannot be mechanized, require regular maintenance
Pitting systems (e.g. Zaï pits/ Chololo pits, Tassa, etc.)	0-5	Bare/shrub land, cultivated land	All agricultural soils	350-600	Even and uneven micro- catchments	1:1-3:1	Demand heavy labour during preparations
Contour ridges /furrows	0-5	Bare/shrub land, grazing land, cultivated land	All agricultural soils not heavy and compacted	350- 750	Even topography	2:1-3:1	Not suitable in heavy and compacted soils, or high rainfall
Trapezoidal bunds	0.25-1.5	Bare/shrub land, grazing land, cultivated land	Agricultural soils with good constructional properties	250- 500	Area within bunds should be even	10:1-30:1	Limited to gentle slopes.
Contour stone bunds with/ without trenches	0-2	Bare/shrub land, grazing land, cultivated land	All agricultural soils	200-750	Even and uneven topography	variable	Only possible where abundant loose stone is available
Contour earth bunds with/ without trenches	0-5	Bare/shrub land, grazing land, cultivated land	Thick soils (at least 1.5 metre deep)	200-750	Even without rills	variable	Not suitable for uneven or eroded land
Eye brows	1-50	Bare/shrub land	Shallow to medium soils	200-600	Even and uneven topography	3:1-20:1	Not effective in very low rainfall areas, cannot be mechanized

Source: Grum, et al., 2015

Table 6. Water harvesting techniques and their suitability indicators (continued)

Water harvesting techniques	**Suitability indicators**						
	Slope (%)	***Land use***	***Soil properties***	***Annual rainfall (mm)***	***Topography***	***C:CA ratio***	***Limitations***
Micro-catchment systems (continued)							
Fanya Juu terraces	5-16	Cultivated land	Moderately deep loamy soils	500-1000	Hill slopes and footsteps	variable	Loss of land for terrace bund, high labour input
Runoff strips	0-5	Bare/shrub land, grazing land, cultivated land	Thick soils (at least 1metre deep)	200-750	Even topography	Less than 2:1	Distribution of water across the strip may not be uniform
Inter-row systems (road catchments)	0-5	Bare/shrub land, cultivated land	Thick soils (at least 1metre deep)	200-750	Even topography	1:1-5:1	Lack of uniformity in water distribution across the cropping area
Macro-catchment systems							
Jessour systems	Moderate to steep slopes	Bare/shrub land, cultivated land	All agricultural soils	less than 250	Even and uneven topography	100:1-10,000:1	Breakdown can occur if no proper maintenance is made
Hillside conduits	Catchment (>10), crop area (0-10)	Bare/shrub land	All agricultural soils	200-600	Hilly or mountainous areas	10:1-100:1	Excess water need to be disposed
Water spreading bunds	Less than 1	Bare/shrub land, cultivated land	Floodplains with deep fertile soils.	100-350	Even topography	variable	Bund breakage are possible in the first season
Micro-dams	Moderate to steep slopes	Bare/shrub land, grazing land, cultivated land	Soils suitable for irrigation	200-750	Not necessarily even, narrow gorge	variable	Expensive structures, suitable topography and geology for reservoir
Cisterns	3-15	Bare/shrub land, grazing land	Deep soils	200-750	Not necessarily even	variable	High construction cost, need stable catchment, siltation and water quality problems
Sub-surface dams	0.2-15	Along streams near cultivated land	Sand bed with shallow rock (2-3 metre from bed)	200-750	Not necessarily even	variable	Difficulties in site selection and calculating water storage
Check dams	Less than 15	Along streams beds (1st to 3rd stream order) nearby cultivated land, 0-700 m distance	Fine loam with less infiltration rate	200-750	Even and uneven topography	variable	Can silt up quickly and need maintenance, improper design causes bank erosion
House hold/farm ponds	0-10	Bare/shrub land, cultivated land	Sandy clay loam with moderate infiltration rate	200-750	Not necessarily even	variable	Siltation/deposition, water loss due to infiltration for porous media
Percolation ponds	0-10	Bare/shrub land, grazing or grass land, along stream beds (2nd and 3rd stream order)	Clay loam, sandy clay loam with moderately high infiltration rate	200-750	Not necessarily even	variable	Need regular maintenance to reduce siltation

Source: Grum, et al., 2015

Table 7. Impacts and trade-offs of the WH technologies as observed at the WAHARA study sites

Water harvesting technology	Study Site	Impact on						Trade-offs	Critical conditions to be met
		Farm management	Agricultural productivity	Food security	Water security	Regional development	Ecosystems services		
Stone bunds	Burkina Faso	organic manure more applied, soil erosion control, run off management	from 1988 to 2002, the impact on crop yields is 30¨%	from 1988 to 2002 an increase of 65% of household food security of 18%	Wells have water during 6 months after building stones bunds in 1998 at Ranawa site	no estimation	more land cultivated, more trees in the field	no estimation	training is needed, intensive labor collective organization
Zaï	Burkina Faso	land rehabilitation, best soil fertility management by using more compost manure	the increase of sorghum yield is 60-78¨%	from 1988 to 2002 an increase of 82% of household food security of 30% (200kg/ha)	may have a long term impact	no estimation	more small ruminants breeding, land cultivated, more trees in the field, fauna diversified	more trade of ruminants and cereal in the market	degraded land, lack of organic manure
Magoye ripper	Burkina Faso	time reduced, soil moisture increased	from the 2 years experiment, the increased of crop yield is 65% with organic manure use	may have an impact if more household use it	no estimation	no estimation	tree regeneration	no estimation	Necessity of little subvention to extend the use
Banka	Burkina Faso	intensive labor used, infiltration, more water	50% of maize yield increase at Ziga	30% of increase	more water to secure crop production	no estimation	impact on fauna	no estimation	subvention of the materials, need training
Bouli	Burkina Faso	intensive labor used, infiltration, more water	the increase of yield is more than 100%	the bouli has the best impact of all WHT applied because the diversification of the production	Water for animals and human use	no estimation	cash crops growing, fauna and tree diversification	no estimation	Need an outside support of funds, social organization required
Percolation pond	Ethiopia		Enhanced soil moisture and created/increased water in wells	Enhanced irrigation and crop yield	Enhanced availability of water	contributed to overall economic development	water used for crop production, livestock watering and biological regeneration	labour cost versus benefit	Availability of excess runoff, and suitable locations
Check dams	Ethiopia		Enhanced availability of water	Enhanced irrigation and crop yield	Enhanced availability of water	contributed to overall economic development	water used for crop production, livestock watering and biological regeneration	cost of construction versus benefit	Availability of excess runoff, and suitable locations
Bench terraces	Ethiopia		Created new cultivable land, enhanced soil moisture	Enhanced irrigation and crop yield	Enhanced availability of water	contributed to overall economic development	The created is used for crop production using both rainfed and irrigated	cost of construction versus benefit	Availability of sources of water and suitable site for bench terrace development

Table 7. Impacts and trade-offs of the WH technologies as observed at the WAHARA study sites (continued)

Water harvesting technology	Study Site	Impact on						Trade-offs	Critical conditions to be met
		Farm management	Agricultural productivity	Food security	Water security	Regional development	Ecosystems services		
Soil Improvement	Ethiopia		Enhanced soil moisture	Enhanced crop yield	Enhanced availability of moisture in soils	contributed to overall economic development		cost of inputs versus benefit	Application of proper soil improvement methods and farm management
Tabia	Tunisia	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Average rainfall: 100-200 mm Neighbouring slopes or spreading system
Jessour	Tunisia	Very high	High	Moderate	Moderate	Moderate	High	High	Average rainfall: 100-200 mm Neighbouring slopes
Recharge wells	Tunisia	Moderate	Moderate	Moderate	High	Moderate	High	High	Average rainfall: 100-200 mm Gabion check dam
Zaï	Tunisia	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	Average rainfall: 100-200 mm Neighbouring slopes
Gabion check dam	Tunisia	Moderate	Moderate	Moderate	High	Moderate	High	High	Average rainfall: 100-200 mm Floods in the wadi channels
Cistern	Tunisia	High	Moderate	Moderate	Very high	Moderate	High	High	Average rainfall: 100-200 mm Neighbouring slopes or spreading system
Zero-till planter	Zambia	High	High	Good	N/A	Highly Possible	Yes	Medium	500-600mm
Strip tillage	Zambia	High	High	Good	N/A	Highly Possible	Yes	Medium	500-600mm
Magoye ripper	Zambia	High	High	Good	N/A	Technology spread to many countries in Africa	Yes	Medium	500-600mm

3. Impact of the WH technologies

All 16 WH technologies tested at the WAHARA study sites have demonstrated their usefulness to increase soil moisture and/or store water for irrigation and as a critical productive resource in an overall farming system and seemed to support rural development. The major observations are summarized in Table 7.

A single WH principle

The WH technologies all make use in a different way of the same basic and universal principle: water always and automatically flows to the lowest point that it can reach. This natural phenomenon is used in WH technologies to retain and capture rainfall water running off a slope to conserve it for useful purposes. They strategically combine natural and man-made features: (1) to block the water flow in its path and (2) redirect it (3) and stored for direct or later use. In this way water can be guided from places where it is less useful to places where it is valued more, and kept there for productive use. Hence, rainfall can be concentrated from larger areas to boost agricultural productivity in smaller areas.

In some WH systems, such as conservation agriculture, the path of the water flow over the surface is minimised (even to virtually zero); the focus is on keeping or maintaining a porous soil structure so that water can quickly flow downwards and be held by the soil rather than remain on top. These WH systems are applied in fields where the amount of water should be optimised for crop production. Some of the captured water may percolate into the aquifer and become useful somewhere downstream. Different technologies can be combined to maximise the WH impact of a field, a whole landscape or even an entire watershed. Local characteristics of the land largely determine which WH technology should be applied where.

Figure 3. A check dam in Ethiopia.
The check dam enables farmers to irrigate. The motorised water pump is crucial. Without it the water harvested at a large expense would not be as productive. The crop is a valuable cash crop (beans) that should help make both the pump and the dam affordable

Conventionally, WH is known to be most prominent in the more arid areas as water shortage there is endemic and the major cause of a highly delicate agriculture. However, underpinning the *universal* principles of WH, actually it is applied in all agricultural zones for optimising the available water in one way or another, as also demonstrated in the four climatically diverse WAHARA study sites. Even in a wet country such as DR Congo there are vast areas where various forms of WH are being practised (Munyuli Bin M., 2003). The soil provides a simple way of storing huge amounts of water at virtually no cost (whereas storage tanks are limited in size and costly) and there are many WH technologies making use of this feature that integrate well with both traditional and modern rainfed farming systems, as is the case for most WH technologies studied at the WAHARA study sites (Table 3). They maintain/enhance the water infiltration capacity of the soil. Some soils are not suitable, for instance clayey soils and shallow soils on a hard rock bed, and the suitable soils need to be managed well to remain suitable. For crop production, including the production of feed crops and grazing, the harvested rainwater is stored:

- Through infiltration. Water in the soil is reachable by crops without further human intervention; crops can absorb hanging water in the root zone or from the ground below through capillary action or from water retainers near the crops such as mulch and clay pots), i.e. reinforcing rainfed agriculture (including through flood water irrigation)
- Through (deep) percolation. Water reaches the aquifer, beyond immediate reach of crops but the recharged aquifer may be for use further downstream or for deep-rooting trees, so generally require people to irrigate the crops unless it reaches a root zone again further downstream
- In an artificial open or closed water buffer (tank, cistern, dam, etc.) useful for irrigation.

Irrigation or rainfed

Irrigated agriculture (i.e. watering a crop) is often understood being the opposite of rainfed agriculture (WAHARA's subject) whereby the crop entirely relies on rainfall. However, the distinction between the two is blurred (Asfaw, 2015). After all, irrigation needs adequate rain to replenish the water resource to irrigate with (unless the water is mined from a non-renewable geological water source). And in rainfed agriculture run-on water and shallow groundwater flow from outside the field can be a considerable supplement to the rain that directly falls on the crop. Often, these water inflows are natural floods re-directed to the field by man (e.g. spate *irrigation*) if not from entirely artificial bulking points (e.g. check dams). Many WH technologies for rainfed agriculture being dealt with in the WAHARA project actually require an irrigation component (Table 3).

So, while supposedly not rainfed, irrigation still needs rain to refill the water sources to irrigate with. The WH dimension of irrigation may often not be obvious either. In many instances though, WH is vital for helping to sustain the rivers, lakes or boreholes that supply the irrigation water. However, the actual water harvesting may take place many kilometres upstream, far away from the irrigated field.

Irrigation can cushion against erratic rainfall, e.g. through supplementary irrigation during drought spells at planting time or during growth of an otherwise rainfed crop, and it allows for growing one or more crops even when it doesn't rain. There are many irrigation systems and technologies also suitable for smallholder farming, both home grown and imported, of different types and capacities and with different required levels of knowledge and investment. The systems should be designed and used such that water and soil losses, e.g. through run-off, leaching and evaporation will be minimal. Similarly to WH, for irrigation beyond household garden level to be worthwhile, the efforts and costs involved normally require the crops to be cash crops.

For livestock production the harvested water needs to be stored mainly as drinking water (and also for other, much smaller water requirements such as cleaning, cooling, feed preparation and medication). The stored water may be used for both irrigated crop and livestock production (as well as for non-agricultural uses) with the bulk of water actually consumed by crops. Where water is extremely limited however, livestock and vegetables may be given priority.

WH impact as observed at the study sites

Increased yields. The WH technologies have had major impacts on farm management and production. Water harvesting effectively combined with some form of land management, by reducing erosion, improving soil health, rehabilitating land or creating new farm land. As a result the scarce water was used in a more productive way; in fact the WH applications have increased yields, or stabilised yields over the years or at least enabled to harvest something where otherwise this would not have been possible.

WH is climate smart. WH allows growing a crop where the climate is too dry to do that without WH, e.g. farmers in Tunisia are productive with only 150-200 mm rainfall. Further WH technologies are climate change resilient; i.e. applying them is a good adaptation strategy to climate change (within certain boundaries as discussed in WP 5.2). While WH is designed to mitigate water scarcity, its features are normally effective during periods of heavy rainfall as well. They help to contain floods and actually turn much of it into useful water rather than a damaging waste. WH technologies should include features to discharge excess water safely. If not, at times of more than normal flooding the application risks to work contrary to what is was designed for and have disastrous consequences in terms of damage to the WH construction works and the land and loss of soil, nutrients and water. For example, Jessour and Tabia systems do have spillways that allow water to cascade to the next jessour/tabia unit. This allows more efficient use of water (on more units), but it also prevents that dykes break during occasional heavy storms.

WH is not a stand-alone solution. By reducing soil erosion, WH technologies inherently have a conserving impact on the land as well, so are part and parcel of sustainable land management (SLM):

- WH technologies such as bunds and zaï are not worth the effort if not accompanied by productivity increases through soil improvements
- Soil improvement measures through mulching and composting:
    - Improved soil organic matter content for increased water holding capacity and to function as a nutrient buffer
    - Improved soil protection through cover against extreme temperatures and erosion (rain drop impact and run-off): reduced evaporation, reduced water and nutrient losses
- In very eroded areas, water harvesting in combination with soil harvesting, land reclamation, terracing, e.g. jessour, bench terraces, contour bunds (Glotzbach, et al., 2011)
- Multipurpose technologies; the same technologies that harvest water, also reduce erosion and harvest (nutrient rich) sediment
- In areas with relatively high rainfall, the emphasis is more on reducing soil erosion, while the same principles in drier areas are applied primarily for making optimal use of the scarce water. In any case, however, both soil and water management are at play together
- Actually there are two types of ponds; one for percolation and one for sedimentation, as well as two types of check dams; one for sedimentation and one for retaining water

Increased labour productivity. Generally, one of the smallholder farmers' biggest constraints is labour. Generally, many farmers have complained about new WH technologies increasing their work load. Combining WH with smart farming approaches making not only the financial investments in WH worthwhile but also the human effort is crucial for WH development. Labour constraints on the farm have a strong gender dimension and improvements can be important especially for women. Investing in soil improving measures, high-yielding commodities and productive inputs and know-how are all important to make WH do-able and sustainable. Together they should increase overall production per man-day of work. One of the major solutions lies in mechanisation, such as through animal drawn reduced or zero-tillage and planting equipment, weed control systems and motorised pumps, but also in farm transport and crop and food processing equipment for value addition of the harvest (see Figure 3).

Under WAHARA, the so-called *Kapandula* ("it cuts") animal drawn ripper was developed in Zambia from the famous *Magoye* ripper (itself an original design by small-scale farm mechanisation experts from Wageningen University and Research Centre) for use in Burkina Faso by farmers who were looking to mechanise the highly effective but manual labour based zaï system. Specifications of this new ripper are presented by Stevens (2015). The tool has been tested at the study site in Burkina Faso and is likely to become important for in-situ WH development. The same *Kapandula* tool was shared with Ethiopia as well in response to an issue raised by the farmers at the stakeholders meeting for the selection of WH technologies. They had observed the problem of moisture stress in their fields as the traditional *Maresha* ard plow only tills the top 15 cm of the soil. They reported a strong need for the introduction of a deeper tillage method that can store more moisture in the soil (WAHARA Research Team Mekelle University, 2012; Sawadogo, et al., 2013)**.** The Kapandula ripper is able -in not too hard soil- to rip furrows deeper than 15 cm to as much as 30 cm depending on the strength of the draft animals.

Figure 4. The *Kapandula* ripper.
The *Kapandula* ripper was developed by WAHARA in Zambia for Burkina Faso for mechanising zaï as requested by farmers. The same technology was also shared with the WAHARA team in Ethiopia as a potential alternative for the traditional *Maresha* ard plow to improve water infiltration deeper into the soil

Increased diversification. Farmers in the WH supported farming systems were able to expand the number of farming enterprises through crop diversification, including the production of tree crops, and in livestock keeping. The larger volumes of water available through WH supported multiple uses, including for household uses and for irrigation of more valuable crops. All in all farming increase resilience and made farming less risky.

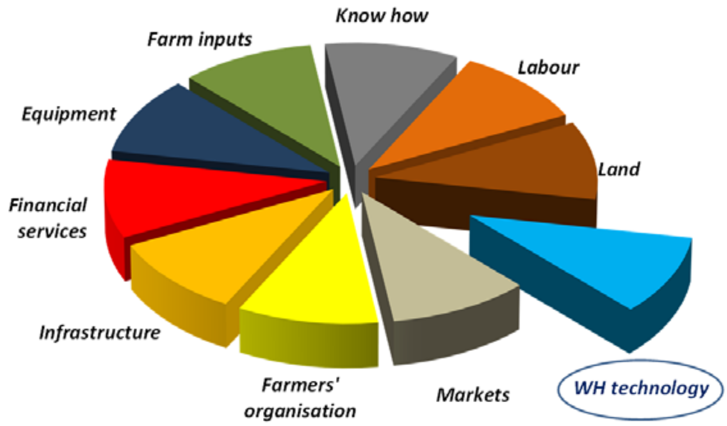
Employment opportunities. Agricultural improvements made possible with the help of WH can make farming more attractive as a livelihood for the youth who generally shun small-scale farming and the poverty associated with it. Furthermore, the general development of agriculture in an area normally stimulates farm input, output and service markets, which are crucial in turn to support that development.

Long-term commitment required. While the some benefits of a new WH technology need to be immediately visible or at least highly plausible for the technology to be attractive to a farmer, it is understood -also by most farmers- that a significant and sustainable environmental and economic impact can only be realised on a long-term basis. Further, it is understood that WH technologies are only part of the requirements that farmers need to be successful. This is illustrated in Figure 6. Outside support is usually mostly needed in:

- Policy support (basically to provide a secure and conducive environment for farming)
- Information sharing (including training and exposure, but also updates that can for instance be provided through radio and telephone services; research should support a constant supply of updated and reliable information)
- Access to new technologies that demonstrate their usefulness
- Access to financial services (to enable and maintain ownership of productive resources)
- Farm input and marketing services.

WH trade-offs. Water harvesting projects can have the negative implications such as:

- More water at certain points thanks to WH can lead to concentration of livestock in these locations, which can result in overgrazing hence a deterioration of the environment



Assets	Some major issues concerning farmers' access to key production assets
Land	Secure land tenure, shortage of farm land, sustainable land management, soil health
Labour	Shortage of labour in peak periods, drudgery of female farmers in particular, access to farm power and mechanisation
Knowhow	Training and extension services, up-to-date information, farmer-to-farmer learning, field demonstrations, farming for business skills
Farm inputs	Availability of agro-dealers, farmers' access to seed, fertilizer, lime, herbicides and pesticides, Knowhow about inputs, quality seed
Equipment	Access to and knowhow of appropriate farm tools and equipment and maintenance services, reliability of equipment
Financial services	Financial literacy, access to loans, insurance, banking services
Infrastructure	Feeder roads, rural electrification, radio, mobile telephone, internet, conducive legal framework and law enforcement
Farmers' organisation	Smallholder representation and lobbying, agri-business groups, bulking centres, group governance and business management skills
Markets	Market facilities and services, marketing information, transport, access to formal markets, marketing skills
WH technology	Improved ground water levels, access to water for irrigation and livestock, water quality, protection against flooding, affordable and locally manageable WH facilities

Figure 5. Water harvesting is a necessary but not sufficient requirement in successful farming

- If WH are too effective, it may result in reduced water available or security down-stream
- Pressure to make WH system worthwhile (e.g. increased need to farm for business) and keep it up (e.g. maintenance, requiring labour and capital) can necessitate life-style changes and need to embark on unknown enterprises, as well as lead to environmental damage (e.g. indiscriminate use of agro-chemicals)
- Traditional communal grazing systems are not compatible with in-situ WH technologies:
  - Risk of trampling of the micro-catchments by the cattle roaming around
  - Investing in WH is not motivating if cattle from others are attracted by the increased production
  - Preventive measures are expensive and/or laborious (e.g. fencing) and complex (e.g. changing community grazing habits/traditional rights)
- If not well laid out, for instance to deal with occasional floods, WH can be more devastating (e.g. in the form of erosion, water loss and damage to property) than without it
- Whereas bench terraces create farm land, other WH structures such as percolation ponds take up space, so there may be a loss of productive land in cases where land is a major limiting

factor. In such situations WH technologies would need to result in a productivity increase on the remaining cropland, in order to compensate for the land taken up by the WH structures.

- (Expansions of) WH technologies may affect large pieces of land that have a different (economic, wildlife, cultural) use, including by third parties (whether individually or communally), and can lead to conflicts (competing claims on resources)
- Standing water can pollute or be infected and become breeding grounds for human and/or livestock diseases as well as introduce the risk of people and livestock drowning.

Some tips to good WH practice

- Make available technologies aimed at minimising water losses in the field. In response to higher rainfall and temperature variation, farmers in Malawi tend to choose risk reducing technologies, including soil and water conservation measures (SWC), especially the wealthier ones and the those with secure land tenure (Asfaw, et al., 2014)
- For optimal irrigation water use efficiency, if irrigation is possible, apply supplementary irrigation to complement inadequate rainfall (Winslow, Shapiro, & Sanders, 2007), eliminate irrigation at times that have little impact on yield (deficit irrigation) and preferably use pressurized irrigation systems such as sprinkler and drip irrigation, targeting irrigation water to plant rooting zones (Kadigi, Tesfay, Bizoza, & Zinabou, 2012)
- Optimise crop water use efficiency:
  - Optimise the choice of crops:
    - Suitable to local growing conditions
    - With water needs that coincide with prevailing rainfall pattern (Yuana, Fengmina, & Puhai, 2003)
    - That are water efficient, mostly early maturing varieties
    - High value and for which a market is nearby. Drought and market risks determine farmers' decision-making in the drylands (Winslow, Shapiro, & Sanders, 2007)
    - A smart mix of crops (consider tree crops, crops for livestock feeding, crops fitting in the rotation scheme, crops for food as well as income)
  - Other measures to optimise farm productivity and build resilience:
    - Know-how, timely farm operations
    - Locally recommended varieties from reliable seed suppliers (possibly certified hybrid seed)
    - Integrated soil fertility management (Fairhurst, 2012)
    - Adequate weed control and pest and disease management
    - Mechanisation adapted to farm size for optimal labour productivity
    - Possibly (supplementary) irrigation
    - Research in Zambia (Arslan, et al., 2014) found timely access to fertilizer being one of the most robust factors for productivity and resilience. They pointed out the importance of good knowledge about the timely use of inorganic fertilizer and that improved crop varieties may perform actually worse under extremely high temperatures. The more old-fashioned approaches legume intercropping and crop rotation were found to be important strategies for offsetting production risks under higher variable rainfall conditions. (Economics and Policy Innovations for Climate-Smart Agriculture, 2015)
  - Increase water use efficiency:
    - Hold water
    - Plant crops near water
    - Supply at times and quantities as required by the crop
    - Supply directly to the crop
    - Reduce evaporation; mulch, soil cover, organic matter, soil structure
    - Reduce percolation/leaching
    - Increase infiltration

- Improve water holding capacity of the soil.

WH suitability conditions

In Table 7 the suitability criteria for WH technologies in general are listed according to six categories:

1. Design of the WH technology
2. Climate
3. Land
4. Other natural (than climate and land)
5. Agricultural (the farming system)
6. Socio-economic (other than agricultural)

Other lists of criteria can be found for instance at WOCAT.

Table 8. Checklist of indicators for the suitability of a WH technology

The required value (or range of values) or the preferred target of each indicator is determined by the WH technology

Category	Indicator type	Indicators
Design of the WH technology	Principle and structural design	Degree of simplicity, scalability, replicability
	Flexibility	Ability to integrate with agricultural operations and farming systems and other (WH) technologies
	Costs - for investment, maintenance, use	Cost types and levels, financing options, payback period
	Inputs - for construction and maintenance	Time, labour, tools, machines and equipment, materials - locally available or imported
	Know-how - for construction, maintenance and use	Skill types and educational and experience levels required
	Safety	For workers, users, public
Climate	Rainfall	Monthly amounts, intensity and variability within and between years against monthly agricultural water needs
	Evaporation	Monthly amounts against monthly agricultural water needs
Land	Soil	Texture, structure and thickness of soil layers, agricultural production potential, spatial variability
	Topography	Space, slope, surface crust, surface roughness, various other features of or on the surface (such as stones, rock outcrops, anthills, gullies, stream beds)
	Vegetation	Types, densities, spatial variability
	Aquifer	Depth, volume, distance to natural surface water, types of surface water
Other natural	Wild life	Biodiversity, risk of pests, fungal diseases and nematodes, and dangerous animals
	Disasters	Probability of earthquakes and storms
Agricultural	Agricultural objectives	Productivity levels (e.g. land, labour, farm, area)
	Agricultural system	Subsistence, market-oriented, commodities (crops, livestock), access to markets, level of organization of the agricultural sector and of empowerment of farmers
	Production types	Use of traditional and modern inputs, level of mechanisation, use of irrigation (type, extent), agricultural land use intensity, drought resistant/tolerant, groundwater recharge
	User rights	Land, water, grazing, forests
	Farmer organisation	Types, membership, services
Socio-economic (other than Agricultural)	Socio-economic objectives	Number and types of beneficiaries, shared values (e.g. food and nutrition security, skills development, employment creation, income generation, gender equality, youth employment), sustainability, community acceptance, activities in competition with farming (e.g. gold panning, migration)
	Social capacity	Level and types of community organisation, skills and resources
	Financial	Risks, costs and benefits (types, volume, quality, timing), profitability, growth potential
	Formal system	Policy, rules and regulation, law enforcement, permits, directives from government and local authorities (e.g. with respect to land tenure, land use, water rights, construction, safety, pollution, natural environmental protection), policy balance between food and cash crops
	Services	Government, private commercial, community, microfinance and credit institutions, warrantage (inventory credit), insurance, farm inputs, equipment, infrastructure, transport, marketing services, research and development, training, information
	Trade-offs and spin-offs	Competing claims (e.g. on land and water use), down-stream impacts (e.g. on water availability and quality, water and wind erosion), competing claims (e.g. between farmers and herders),

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