WAHARA - Report Series

WAHARA FINAL PUBLISHABLE SUMMARY

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WAHARA

Date: 20-04-2016
Report number 36

Series: Scientific Reports

This report was written in the framework of the WAHARA project – www.wahara.eu

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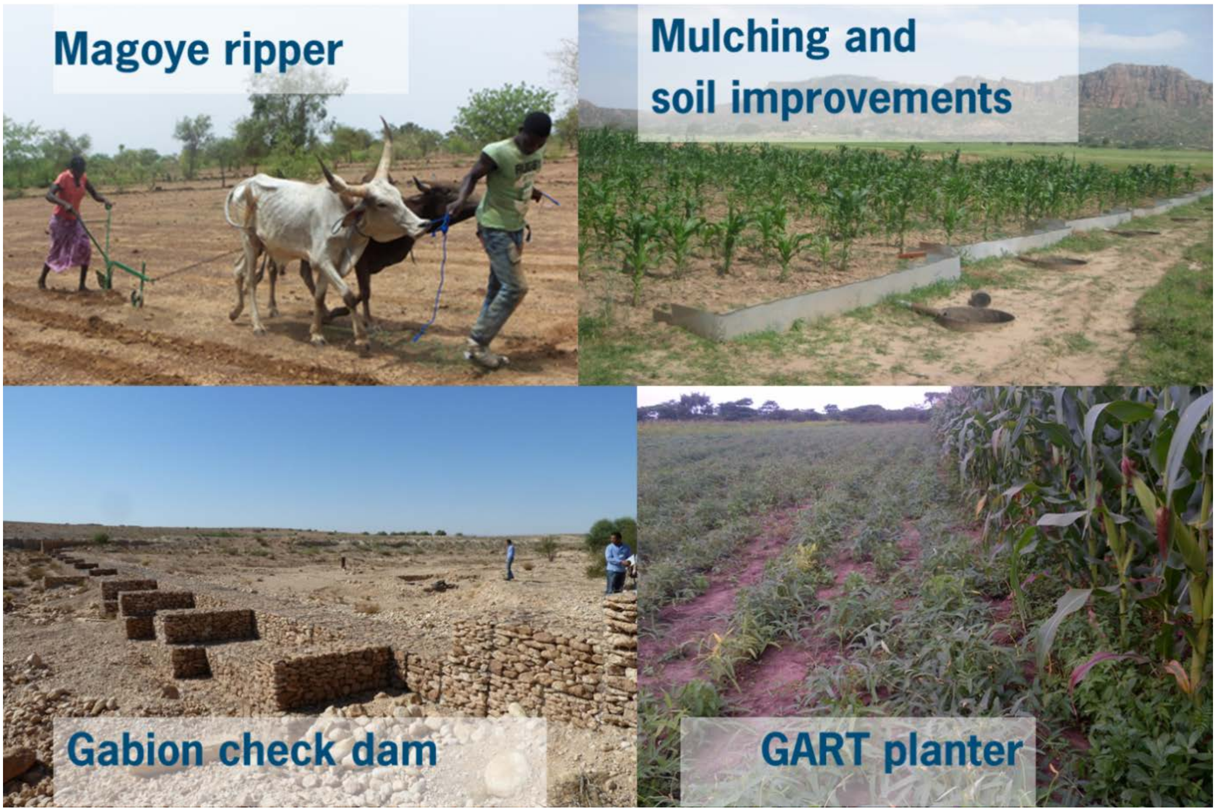

April 2016

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WAHARA Executive summary

Food production in Africa is under pressure by population growth and climate change. The growth of food production has not kept pace with population growth in recent decades. Two key challenges concerning agriculture converge: how will Africa feed its growing population? And how will African agriculture cope with climate change? Overcoming these challenges is the key to food security. In addition to the agricultural challenges, a third key challenge is: how to improve water security of rural Africans? Water harvesting can be a way to overcome these challenges.

The WAHARA (WAter HArvesting for Rainfed Africa) project aimed to introduce innovative appropriate water harvesting technologies that fit in existing rain fed farming systems in different parts of Africa and that are integrated in local livelihood systems. WAHARA also aimed to assess the impact of the different technologies – both on-site and downstream. In WAHARA there was also emphasis on understanding and developing pathways to implement water harvesting at larger scale. The overall project aim was to develop solutions applicable beyond local study sites and indeed across the continent. In order to achieve this, study sites were selected that are representative for rainfed Africa: Tunisia in the North, Burkina Faso in the West, Zambia in the South and Ethiopia in the East.

Water harvesting (WH) technologies for each site were chosen using participatory stakeholder workshops. Selected water harvesting technologies were adapted to fit local conditions, were implemented for testing, and their performance was monitored as well as evaluated in collaboration with stakeholders. Models were developed to assess the socio-economic basis for intensified water. The main results were that in all four study sites the monitoring results showed that water harvesting had a positive effect. In several of the study sites, it was found that crop yield increased by a factor of two or more if water harvesting was used. Monitoring results also indicated that under drought conditions, the use of water harvesting techniques enables farmers to still obtain a reasonable yield, and thus mitigate the effects of drought on livelihoods of farmers. Modelling showed that in-situ WH generally is profitable to farmers across study areas. Positive externalities may need to be considered to justify investment in ex-site WH technologies (e.g. Tunisia) or should accrue to farmers owning plots in valley bottoms (e.g. Ethiopia). Time series analyses demonstrated significant contribution of WH technologies to mitigating the effects of dry spells and enhance food production.

WAHARA results overall indicate that water harvesting technologies not only work but have great potential. And, the expertise to actually do this is in principle available too. However, while the concept of WH, retaining runoff for productive use, is universal and simple, making it work is not. It requires adjusting to conditions that cannot be changed while making smart adjustments among those that can be. However, the bio-physical and socio-economic conditions are numerous, interconnected, often conflicting, and they differ widely between locations, even at short distance, as well as over time. Moreover, the real adaptation challenge is not to make a WH technology *work* under new conditions but to make it *worthwhile*; the expected benefits must be realised with limited resources, without taking a lot of time and for enough people. Introducing a new WH technology must demonstrate direct economic sense locally. Critical for sustained economic success are policy support, local ownership, local skills and inputs, access to adequate finance, profitable markets, private sector involvement and availability of services as well as professional farmers who can make the WH investments profitable. This explains why WH doesn’t spread easily; there can be no adoption without adaptation.

To farm successfully, one must be an innovator, certainly when to survive under straining conditions, so always with the pressure to stay productive. Farmers’ innovations are testimonies of success, and demonstrate farmers have the ability to adapt. However, they cannot do it without having ownership of productive resources and access to a range of farmer services. What works is putting the farmer at the centre of it all, respecting his agency, treating him as a client rather than a beneficiary. When farmers are convinced about the benefits of WH technologies to productivity and income, they will take them up, innovate and adapt them to their specific needs. That’s when WHTs truly spread. This core process can be supported by facilitating farmer-to-farmer learning systems and linking them with formal education & research systems.

1. WAHARA Project context and objectives

Food production in Africa is under pressure by population growth and climate change. Water plays a crucial role in food production, and in Africa, compared to other continents, the least is produced per unit of water used. Africa's water reserves are small compared to that of other continents, and Africa is furthermore characterised by large disparities in rainfall distribution and water availability across the continent (Joto Africa, 2009). Due to population growth, water scarcity is on the increase. Moreover, Africa is the only continent where growth of food production has not kept pace with population growth in recent decades; yet performance of the agricultural sector is crucial for long-term growth prospects (UNECA, AU and AfDB, 2000), not least because 80% of Africans rely on agriculture for their livelihoods (Alliance for a Green Revolution in Africa, 2009).

The vast majority of African farmers rely on rainfall for food production: 95% of agricultural production in Africa comes from rainfed areas (UNEP, 2009). Productivity levels are low and grain yields oscillate typically around 1 ton per hectare. There is an important yield gap between experimental results and farmers' reality (Rockström et al., 2010). The key to closing the gap lies in improved water and nutrient management. African countries on average only store 4% of annual water flow (WWDR3, 2009), and a low water buffer means high vulnerability to both droughts and floods. Risk of climatic anomalies in Africa will even increase as a result of climate change (Conway, 2009). By 2020, 75-250 million people may be exposed to increased water stress due to the combined effects of climate change and increased demand (IPCC, 2008).

Two key challenges concerning agriculture converge: how will Africa feed its growing population? And how will African agriculture cope with climate change? These challenges are recognized by Africa's Leaders, and overcoming them is the key to food security. The Africa Water Vision calls for investment in water resources management. The Comprehensive Africa Agriculture Development Programme (CAADP, www.caadp.net) and the Alliance for a Green Revolution in Africa (www.agra-alliance.org) call for a boost in agricultural productivity. The CAADP's first pillar rests on improvements in land and water management. The scope for a boost in agricultural productivity is greatest in rainfed agriculture: an extensive review of opportunities shows that yield improvements of rainfed crops of about 100% can be attained, against 10% for irrigated crops (Pretty and Hine, 2001). Food security would improve as a result of increased productivity of rainfed agriculture, but will especially benefit from increased resilience brought about by improved buffering of water.

In addition to the agricultural challenges, a third key challenge is: how to improve water security of rural Africans? Less than half of rural Africans currently have access to secure water (e.g. improved boreholes, wells or treated surface water) (MacDonald et al., 2009). Yet, the wider socio-economic benefits of safe water and adequate sanitation (improved health, livelihood security and poverty reduction) have, in 2004, been estimated at US$3-4 per US$ invested, with the highest returns in Africa (WHO, 2004). Again, buffering of water resources is the answer to the challenge, and water harvesting in rural areas (WH) is one of the main ways to do that.

To contribute to providing solutions to these 3 key challenges, the WAter HArvesting for Rainfed Africa: investing in dryland agriculture for growth and resilience (WAHARA) was started in 2011, with a project duration of 5 years. Its main aim was to develop innovative appropriate WH technologies for different geographical regions of rainfed Africa.

Many definitions and classification systems exist of water harvesting (WH) technologies. UNEP (2009) defines water harvesting as: "the collective term for a wide variety of interventions to use rainfall through collection and storage, either in soil or in man-made dams, tanks or containers bridging dry spells and droughts. The effect is increased retention of water in the landscape, enabling management and use of water for multiple purposes". Recent classification systems distinguish between *in situ* and *ex situ* water harvesting (Oweis et al., 1999; Ngigi, 2003; Vohland and Barry, 2009), but the first level of classification could just as well be based on the source of water, the type of system applied, the time span between capture and use, and the type of use (Siegert, 1994; SIWI, 2001). *In situ* WH (also known as water conservation) utilises the local soil as storage medium, while *ex situ* WH systems include a water storage or retention component which is tapped for both temporally and spatially dislocated usage from the rainfall collection area.

There are at least four arguments for water harvesting: climate change adaptation using natural storage, scope for water quality improvement, recirculation in the water chain, and support functions for ecosystems and agriculture. Some forms of water harvesting technologies (WHT), such as measures to recharge groundwater or to harvest fog would not fit the definition given above. In a more all-embracing definition, in WAHARA we defined water harvesting technologies as: “the collective term for a wide variety of low-cost interventions which are primarily or secondarily intended to collect natural water resources which otherwise would have escaped from human reach, and buffer them through storage and/or recharge on or below the soil surface. The effect is increased retention of water in the landscape, enabling management and use of water for multiple purposes. Water harvesting technologies can either operate either as independent units, or require embedding in a larger system of environmental management interventions, or require specific natural conditions”.

In rainfed agriculture, rainfall is the most prominent random parameter beyond farmers’ control. In arid climates, where crop water needs often exceed total rainfall, WH can enable agriculture by concentrating water from a larger area without the need of depleting groundwater resources. This role can be extended to semi-arid and dry sub-humid climates, where it is not the amount of rainfall that limits rainfed production but rainfall variability (Rockström et al, 2010). Rainfed agriculture in those regions is subject to large inherent water-related risks, which make farmers less likely to invest in nutrients and other production enhancing inputs. Yields on farmers’ fields are therefore typically found to be only 20-30% of their potential levels as obtained in experimental plots: the yield gap (Rockström et al., 2010). Under such circumstances less than 30% (on degraded land only 5%) of rainfall is used as productive transpiration by crops (Rockström, 2003). Improved rain water management includes increasing plant water availability by *in situ* and *ex situ* WH and evaporation management, and increasing plant water uptake capacity by integrated soil, crop and water management (Rockström et al., 2010).

WH presents highly adapted, flexible, easy to understand and implement, low-cost solutions to the productivity, climate adaptation and water security challenges, primarily by building water buffering capacity. WH technologies include centuries-old systems developed by local knowledge but also innovative new approaches. Together, these approaches hold great potential to boost economic development and sustain livelihoods in the regions of Africa dependent on rainfed agriculture. However, to unlock this potential, and despite the fact that WH has over the years received substantial interest from the research community, there is still considerable need for further advancement of knowledge:

- Although the validity of the WH concept has proven itself time and again, WH technologies have so far remained local solutions. Recent success-stories in scaling of WH, like the Green Water Credits mechanism (Dent and Kaufmann, 2007), have triggered the question: ‘what is the potential of WH for Africa?’
- How to select appropriate technologies for areas with potential for WH development?
- As WH technologies have mostly been studied only in the areas where they were originally developed, can they be adapted to different environmental and socio-economic conditions, and what would – under those circumstances – be their effectiveness? More in general, how does development of WH influence the provision of ecosystem services?
- Is there an economic limit to scaling WH technologies in a catchment (Ngigi, 2003)?
- Although socio-economic and political conditions necessary for WH are qualitatively known, no quantification has been made yet to understand and support individual decisions by farmers (Vohland and Barry, 2009). Furthermore, those factors have not been combined with biophysical factors in models to evaluate feasibility of WH technologies.

- Whereas it is generally accepted that WH technologies improve water buffering and consequently reduce vulnerability to climate anomalies (it is their *raison d'être* after all), little is known about their economic viability under climate change scenarios.
- What strategy should be taken to aid learning and action related to WH technologies and to disseminate successful innovations?

WAHARA contributed to closing these knowledge gaps, by studying local WH solutions in 4 study sites throughout Africa from a transdisciplinary perspective that takes into account not only bio-physical aspects, but also socio-economic aspects and political conditions. The project worked closely together with stakeholders, to make sure that selected solutions really met their needs. The effectiveness of WHT was assessed under different environmental and socio-economic conditions, and was modelled for various scenarios, considering drivers such as population growth, urbanisation and climate change. By combining results from the 4 sites, the potential of WH for the whole of Africa was assessed.

To develop innovative appropriate WHT, which contribute to food and water security in rainfed Africa, WAHARA focussed on four issues:

- WH technology *design*: Design WH technologies that have synergies with existing rainfed farming systems (i.e. that are sustainable).
- WH technology *impact*: Assess at catchment scale the on-site and downstream impact (environmental services) of WH technologies.
- WH technology *integration*: Develop criteria for sustainable impact on improving livelihoods with WH technologies under various pressures, considering economic development; guidelines for adapting WH technologies across rainfed Africa.
- WH technology *learning and action*: Develop guidelines to facilitate stakeholder learning and action about WH technologies in different (biophysical and socioeconomic) conditions; dissemination products targeted to stakeholders from local to international level will be developed and distributed, and guidelines to enable learning and action on WH will be prepared for third-party follow-up initiatives.

The project aimed to develop solutions applicable beyond local study sites and indeed across the continent. In order to reach this objective, study sites were selected that are representative for rainfed Africa: Tunisia in the North, Burkina Faso in the West, Zambia in the South and Ethiopia in the East. Apart from the geographical spreading, a wide range of environmental and socio-economic conditions is also covered by these countries.

As Table 1 shows, the 4 countries represent different rainfall conditions: seasonally humid in Ethiopia, sub-humid in Zambia, semi-arid in Burkina Faso and arid in Tunisia. In all 4 countries, rainfall is seasonal, especially in Burkina Faso and Zambia, resulting in seasonal drought. Whereas the rainy season in Burkina Faso falls in the hot summer period, the scarce rains in Tunisia fall mostly in the cool winter period. The study sites are located in rural areas within these countries, which still rely heavily on agriculture. In the poor developing countries Burkina Faso and Ethiopia more than 80 % of the population is still rural; in Zambia this figure is slightly lower at 64%, whereas in Tunisia this has now declined to 34 %. The agricultural sector in these countries is withdrawing by far the largest amount of water, with 94, 86, 82 and 76 % of total water withdrawal in Ethiopia, Burkina Faso, Tunisia and Zambia respectively.

Table 1 Basic socio-economic and land and water use indicators in the four countries with study sites.

Indicator	Unit	Ethiopia	Burkina F.	Tunisia	Zambia
Total national area	million ha	110	27	16	75
Under arable & permanent crops	%	14	19	25	7
Total population	million	81	15	10	11
Population density	persons/km2	73	56	62	15
Percentage population rural	%	81	84	34	64
Agricultural production	% of GDP	46	33	10	19
Average annual rainfall	Mm	848	748	207	1020
Rainfall seasonality index*	-	0.77	1.04	0.50	1.07
Renewable water resources**	m^3/capita/yr	1506	871	411	9630
Withdrawal as % available fresh water resources	%	4.6	6.4	61.3	1.7
Agricultural water withdrawal	%	94	86	82	76
Irrigation potential	1000 ha	2700	165	560	523
Area equipped for irrigation as % potential	%	11	15	70	16
Idem as % cultivated area	%	2.7	0.5	8.0	3.0

Source: FAO Aquastat, 2009.

* Walsh & Lawler (1981), calculated with data from www.worldclimate.com for Addis Ababa, Ouagadougou, Tunis and Lusaka.

** World average is about 7000 m^3/capita /year (Nasr, 1999).

2. WAHARA main results

2.1 Methodology

WAHARA employed the same participative approach in all 4 study sites to allow comparison of results between sites. This approach consisted of several main steps:

- **Review of existing information** on study sites, water harvesting technologies and water-related challenges in African farming systems.
- **Stakeholder involvement**. In each country WAHARA did an inventory of main stakeholders/key players and formed stakeholder alliances/platforms in and around the study sites.
- **Selection of WHT for testing**. Water harvesting technologies for each site were chosen based on an understanding of the sites, a match with a global inventory of technologies and using participatory stakeholder workshops.
- **Implementation and monitoring** of the selected WHT. The performance of selected technologies was monitored as well as evaluated, and discussed with the main stakeholders.
- **Upscaling and integration**. Models were developed to assess the socio-economic basis for intensified water harvesting as well as the physical interaction with the catchment. On the basis of the analysis of the four study sites the scope for wider application in different contexts was assessed and translated into guidelines for application and adaptation of water harvesting technologies. WAHARA actively disseminated experiences and results.

These different steps, and their results, are described in the following sections.

2.2 Review of existing information

WAHARA started off with a review of existing information at African scale, as well as at the scale of the 4 countries and study sites. This review dealt with several aspects relevant to water harvesting, using different methods for each. The main activities in this phase can be summarised as follows:

1. Literature review of WHT in Africa, in the 4 countries and in the study sites,
2. Summary of existing information about the 4 study sites in study site descriptions,
3. Development of a Quick Scan tool to assess suitability of different categories of WHT based on existing information,
4. Investigation of socio-economic factors that are relevant for WHT, using a farmer household survey,
5. Scope for WHT in Africa, based on existing information.

Each of these topics is discussed below.

1 <u>Literature Review</u>

An inventory of existing water harvesting technologies (WHTs) was done and a literature study about the use of WHT in Africa was made. This literature review was based on three main components: database research, own sources and *grey* literature documents. In particular, two reports were made, one gave an overview of WHT technologies that are used in Africa, based mainly on Anglophone literature. The other report added to this by focusing on Francophone literature, and in particular on WHT in Tunisia and Burkina Faso. Both reports used the same 5 categories of WHT to summarize the available information, which has also been used by some other authors (Prinz, 1996; etc.):

- Micro-catchment methods to collect water at farm and field level;
- Macro-catchment methods to collect water at the watershed level;
- Flood water harvesting methods;
- Atmospheric water harvesting methods;
- In situ soil moisture conservation methods.

Table 2. Example of information summarized for WHT used at micro-catchment level

Climate	**Country**	**Buffer**	**Water source**	**WHT**	**Indigenous / New**	**Labour/Mechanic intensive**
(South Sahelian, annual rain: 400 to 700 mm)	Burkina Faso	Soil storage in-situ	Runoff	Tied stones lines (*Cordons pierreux isohypses cloisonnes*)	I	Low
(South Sahelian, annual rain: 400 to 700 mm)	Burkina Faso	Soil storage in-situ	Runoff	Stone dykes (*Diguettes filtrantes*)	I	Low
(South, annual rain < 200 mm)	Tunisia	Soil storage in-situ	Rainfall/ Runoff	*Hoffra*	I	Low
(centre: annual rain 200 to 400 mm)	Tunisia	Soil storage in-situ	Runoff	Earth dykes + "draining-off" (*Banquettes en terre à extrémité déversantes*)	N	Low
(centre: annual rain 200 to 400 mm)	Tunisia	Soil storage in-situ	Rainfall	Bourrelets	N	Low
(Arid to semi-arid)	Tunisia	Soil storage in-situ+ cistern	Rainfall/Runoff	Enclos-Tabias	I	Low
(Arid)	Tunisia	Soil storage Ex-situ	Runoff	Mescat + Mankat	I	Low
(Arid to semi-arid)	Tunisia	Tank	Rainfall/ Runoff	*Majel/ Fesquia.* (Cisterns)	I	Low
(Sub-Sahelian: annual rain 400 to 700 mm)	Burkina Faso Ethiopia	Soil storage in-situ	Runoff	Stone dykes/rock lines (*Diguettes filtrantes/cordons pierreux*)	I	Low
(North Sudanien rain : 790 mm)	Burkina Faso	Soil storage in-situ	Runoff	Hedgerow barrier system	I	Low
(Sub-Sahelian: annual rain 400 to 700 mm)	Burkina Faso	Soil storage in-situ	Runoff	3 types of Rock lines (*cordons pierreux*) :	I	Low

These reports were then summarized further. For each WHT, only the most important indicators as derived from the literature sources are given, as far as this info was available in these sources:

- Climate: climate setting (arid, semi-arid, sub-humid etc.),
- Country: geographical position,
- Buffer: medium for water storage,
- Water source: Rainfall, runoff, or flood,
- WHT: Name or type of the technology,
- Indigenous or new: Traditional or newly introduced technology,
- Labour or Mechanic intensive: Implementation constraints.

Table 2 gives an example for WHT at micro-catchment level.

The overall conclusion from the literature review was that the African continent is very rich in success stories about various water harvesting and soil conservation technologies. They vary from macro and micro-catchment and floodwater harvesting to atmospheric and in situ water conservation technologies. The existing well known traditional and indigenous practices have been either improved and/or new technologies have been introduced to complement them. The same trends have been also observed in all the study sites. However, as Ethiopia and Zambia study sites are located in more humid climates, more soil conservation technologies are in use whereas the water harvesting practices are frequently encountered in Tunisia and Burkina study cases where the climate is drier. The high level of the local know-how of the stakeholders (especially farmers, engineers, etc.) and their willingness to be fully involved in the different steps of the implementation of the project (in a real partnership and participatory approaches) were key elements in the implementation of the various components of the project in all the study sites.

2 Study Site descriptions

Study Site descriptions were made to characterise and describe the study sites and to assemble existing information about them, using a standardised template. The Study Site Descriptions included the following topics: General information, bio-physical and socio-economic features, institutional and political setting and stakeholders, water resources and water use, water harvesting techniques used in the country and in the study region, past and on-going projects especially related to water harvesting, available time series data and maps. With this information an overview of the sites is obtained that provided all the background information that was necessary to understand the study sites and the problems that are experienced in these study sites, with a focus on water use and water availability.

The results showed that the four study sites (Burkina Faso, Ethiopia, Tunisia, Zambia) of the project covered a wide spectrum of biophysical and socio-economic conditions in Africa. The climate ranged from arid to sub-humid, and average rainfall varied from 150 mm (in Tunisia) to 800 mm in the other sites. Population density also differed between sites. However, common features are also present such as the variability of climate and the associated risks of disasters such of drought and flooding. In addition, a major factor in all sites is the low resilience of the rural populations to adverse extremes as well as low agricultural water productivity. WH technologies used in the different sites were different due to the local conditions, but sufficient similarities exist to allow comparative analyses. Table 3 summarises characteristics of the 4 sites.

Table 3. Overview of study site characteristics

	Burkina	**Ethiopia**	**Zambia**	**Tunisia**
Area (km2)	5000	2400	2300	1200
Rainfall (mm)	400-800	550-800	700-800	150-220
Climate	Sahelo Sudanian	Semi arid	Tropical continental	Arid
Population	140000	236000	73000	25000
WH[1]	Zai, ados, half moon, bund, cropping methods	Diversion, spate, bunds, ponds, terraces, dams, eyebrow basins, deep trenches, cropping methods	Dams, cisterns, storage structures, quarries, cropping methods	Jessour, tabia, recharge structures, cisterns
Crops	Mainly Sorghum, millet	Mainly Barley, maize	Mainly Maize, cotton, groundnuts,	Mainly Olive, cereals
Water resources	Rain, dam, aquifer	Rain, springs, water storage,	Rain, wells, streams,	Rain, aquifer
Water use	Rainfed agriculture, irrigation, domestic use	Rainfed agriculture, irrigation,	Rainfed agriculture, drinking, livestock	Drinking, agriculture, industry,

[1] For explanation of WH names see WAHARA report 16

3 Quick Scan tool

An analysis of variations in hydrology, driven by climate, allows both broad scale comparisons of water harvesting methods across Africa (or globally) and advice down to a community scale. The QuickScan tool that was developed in WAHARA is based on available climatic and land use data, and is also able to take account of local knowledge, comparing the opportunities for alternative WHT, based either on innovative technologies or transferred from other areas with a similar hydrological regime.

Specifically, the QuickScan tool

1. makes use of publicly available climate and other data to put particular areas into their broad regional context using a water balance model, computing the shortfall of reliable rainfall for rainfed crop production and the consequently required ratio of water harvesting area to crop harvesting areas,
2. provides initial advise to researchers and stakeholders on options for improving water use and sustainability of crop production by making the model applicable at a more local scale, making use of more detailed, finer scale information provided at local level, to suggest a range of possibly suitable alternative water harvesting strategies and compare them with current practice.

This brings together meteorological, topographic, soils, population and economic inputs, as sketched in Figure 1, although not all of these are fully incorporated in the tool.

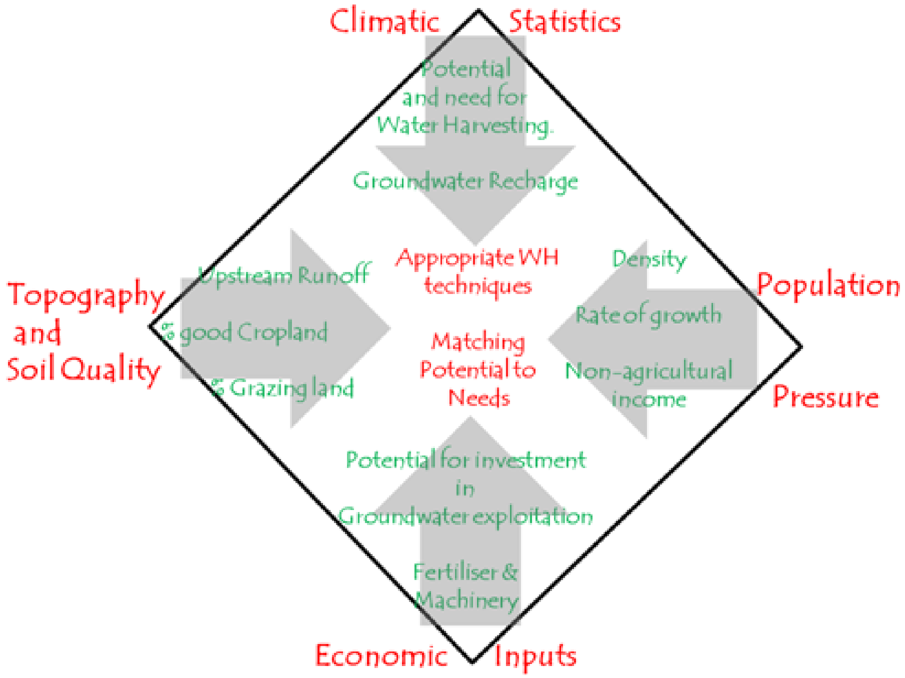

Figure 1: Outline of the QuickScan tool

The quick-scan tool can be used to quickly assess which kinds of WHT could potentially be used where in Africa. The tool has been applied for the current climates associated with the four study sites, in Ethiopia, Burkina Faso, Zambia and Tunisia.

Results showed that there is a spectrum of increasing crop reliability from Tunisia to Ethiopia to Burkina Faso to Zambia, and that Tunisia shows greater year to year variability than the other sites, as the range of deficits that occur is largest.

Figure 2 shows estimated grain yields, calculated for millet within the cropped area, for the four site areas. It can be seen that increasing the collecting area (CAR) has a modest effect on yields, and more so in the more arid areas.

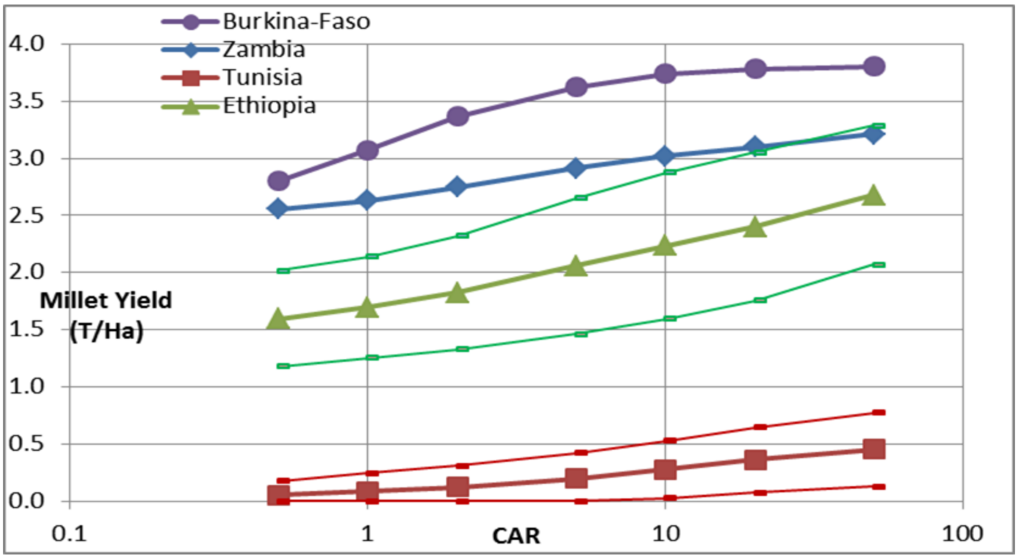

Figure 2: (a) shows forecast grain yields from the cultivated area, based on data for millet, for different cropped area ratio (CAR). CAR is defined as collecting area divided by cropping area.

It should be realised that continental assessments such as those performed by the Quick scan tool cannot take local (bio-physical) conditions into account, and therefore a choice for a certain type of WHT should always consider these conditions to determine whether local conditions are sufficiently accounted for in the tool. Furthermore, in years with below average rainfall the need to use WHT is larger, and the Quick scan tool does not take the distribution of rainfall during the growing season into account. Finally, it is not possible to include socio-economic aspects adequately in the Quick scan tool developed in WAHARA. Therefore, socio-economic aspects need to be considered at smaller scale, e.g. at the scale of study sites. In this respect, the Quick scan tool provides some indication about what WHT could be suitable from a bio-physical point of view, while a deeper assessment of socio-economic situation at study site scale should then be used to narrow down and determine which of these WHT would be suitable from that point of view.

The tool is available to other interested parties and was for example already shared with the Afromaison project (http://www.afromaison.net/). It also played a role in upscaling WAHARA results from study site level to continental level.

4 Household Survey

Household surveys have been conducted to obtain socioeconomic data on households in the project study sites. The main objective was to perform statistical and spatial analyses of biophysical and socio-economic factors that characterize livelihood strategies, natural resources and land management practices. The contextual situation of selected sites was analysed with the objective to understand what the preconditions and limitations are for water harvesting (WH) technology development. For all study sites included in the project, biophysical characteristics of the local environment that affect WH potential were inventoried. Stakeholder group characteristics (livelihoods, resources, farming practices) have been sampled through a farm agro-socio-economic survey among individual group members.

A generic questionnaire has been designed and adapted to the local context of each country. The questionnaire allows gathering data at the household level in order to i) describe the farming system ii) analyse the capital assets and iii) identify and assess WH techniques. The sampling method adopted is based on the total population structure that is a bit homogeneous and defined by the presence of different zones. To choose the final sample the representatively and the heterogeneity of local population have been respected. The survey household outcomes have been used to feed Sustainable Livelihood Approach in order to evaluate patterns and driver impacts on livelihood condition. All the above mentioned collected data have been combined to assess the local potential for WH technology development.

Results show that farm households in different study sites rely heavily on agriculture for their livelihood. The rainfed farming system has always been of crucial importance in generating much (more than 50%) of the farmer’s income. Land, and amount and distribution of rainfall are two of the basic inputs that determine agricultural productivity. Small and medium farming systems are the dominant production system in the different study areas. The average land holding is 1.15 ha, 1 ha, 10 ha and 23 ha respectively in Burkina Faso, Ethiopia, Tunisia and Zambia. The fact that most farms are small has negative implications for mechanization and economies of scale. The small land holding coupled with deteriorating soil fertility and highly variable/erratic rainfall are a major challenge to meet the basic subsistence needs of households and, hence, their livelihood.

WHTs in the study areas were found to be important in terms of harvesting enough water for both domestic and irrigation needs. A significant number of farmers in the study areas started to obtain higher yields after they adopted WHTs. Although it is difficult to measure the changes in productivity due to WHT due the lack of enough observed field data, rough approximations indicate positive impacts. However, several issues constrained their success, such as: i) lack of intra-sectoral integration particularly in the agricultural sector as well as inter-sectoral integration leading to inefficiency and, sometimes, conflicts of interest between sectors, ii) limited involvement and participation of local actors and communities leading up to weak partnerships between and amongst stakeholders (those of the state and of civil society); and iii) low economic efficiency due to lack of cooperation and synergy between activities and sectoral interventions.

5 Scope for WHT

Previous work (described above) showed which WHT are currently used in the WAHARA study sites, and what the attitude of stakeholders towards WHT was. Furthermore, the Quick Scan tool gave information on which types of WHT would potentially be suitable in each study site, based mainly on bio-physical characteristics. However, socio-economic aspects need to be considered at smaller scale, e.g. at the scale of study sites. In this respect, the Quick scan tool provided some indication about what WHT could be suitable from a bio-physical point of view, which was complemented by socio-economic insights resulting from household survey and stakeholder workshops (see section on stakeholder involvement). Based on what stakeholders said they thought important in WHT, study site teams made a pre-selection of WHT that would potentially be useful for the study site. This pre-selection included some WHT that are already practised in the area, but that could be adapted and/or adopted more widely, and it also included some WHT that are new to the study site (e.g. from other WAHARA study sites). For all 4 study sites, a number of potentially suitable WHT have been identified, demonstrating that all study sites have potential for WHT.

Burkina Faso

Ethiopia

Zambia

Tunisia

Figure 3. Impressions of stakeholder workshops in the 4 sites

2.3 Stakeholder involvement

Stakeholder involvement in WAHARA started very early in the project, and played a crucial role throughout the lifetime of the project. As a first step, a stakeholder analysis was performed to identify in a structured manner who were the stakeholders in each study site. Soon after this, a first stakeholder meeting was held in each study site. Thanks to these workshops, stakeholders were informed about the

WAHARA project, and expressed their willingness to collaborate. They also expressed their opinions about WHT, demonstrating that they do already use WHT and are aware of the crucial role that WHT can play to grow crops in arid and semi-arid environments. Figure 3 give an impression of the workshops in the 4 study sites

After the first stakeholder workshop, a second workshop was held in all sites to select WHT for implementation (see next section). Selected WHT were adapted, implemented and monitored in collaboration with stakeholders. As mentioned before, an household survey was also held, with the purpose of obtaining socioeconomic data on households in the study sites. At the end of the project, project results were presented to stakeholders, and were discussed with them. This was done in the different study sites, but also through a dedicated dissemination event at the final plenary meeting.

2.4 WHT selection

The overall selection methodology that was used in WAHARA can be summarized as follows (see figure 4):

- Find out what stakeholders thought about WHT. Whether they are familiar with it, what they would like to achieve with it, what criteria they apply to decide whether to use is etc. This was done in the first stakeholder workshops
- Select some technologies to describe with WOCAT (World Overview of Conservation Approaches and Technologies – www.wocat.net, see next section) questionnaires in each country based on the feedback received at the first stakeholder workshop.
- Fill the WOCAT questionnaires for technologies as well as for the approaches associated with these technologies, with input from stakeholders.
- Search the WOCAT database for any other technologies that seemed promising for the study sites, based on the aims the stakeholders have. Generally, each practice should have an impact on yield of crops, sustainability and livelihoods.
- Organization of a stakeholder meeting to select WHT according to a standardized methodology. Stakeholders always included local land users, but also (in varying degrees between sites) provincial or communal extension services; political leaders; local authorities; researchers and farmers’ organisations.

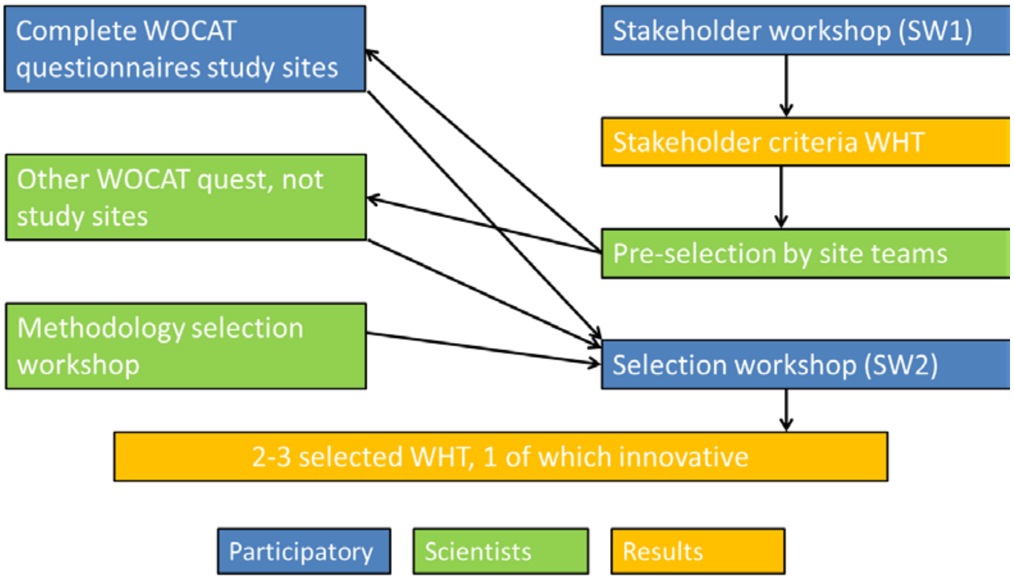

Figure 4. Overview of selection methodology

WOCAT is an established global network of Soil and Water Conservation (SWC) specialists, contributing to Sustainable Land Management (SLM) and WHT worldwide. WOCAT’s goal is to prevent and reduce land degradation through SLM technologies (including WHT) and their implementation approaches. The main objective of SLM is to make human coexistence compatible with nature in the long term. The WOCAT network provides tools that allow SLM specialists to identify fields and needs of action and share their valuable knowledge in land management. The tools aim to assist these specialists in their search for appropriate SLM technologies and approaches and support them in making decisions, both in the field and at the planning level, as well as when up-scaling identified best practices. WOCAT is increasingly being used to describe SLM technologies and to share knowledge about these worldwide, see e.g. Schwilch et al (2012).

In the WAHARA project, the WOCAT questionnaires on SLM technologies (QT) and approaches (QA) were used to describe pre-selected WHT. In each study site, several WHT and their associated approaches were described using the WOCAT questionnaires, based on the outcomes of the first stakeholder meeting. The completed questionnaires were included in the online WOCAT database so that they are available to anyone, and were also used as input in the selection procedure of stakeholder workshop 2.

Table 4. WHT selected for test implementation in the 4 study sites

	Burkina Faso	**Ethiopia**	**Zambia**	**Tunisia**
1st selected WHT	Zaï	Series of Hillside Cistern with bench terraces	Minimum-Till Basin Method	Jessour
2nd selected WHT	Stones lines	Percolation/sediment storage ponds with hand dug wells	Conservation Tillage with Magoye Ripper	Gabion check dam
3rd selected WHT	Magoye Ripper to combine with use of compost manure	Check dams	Strip Tillage Conservation Farming	Tabia
4th selected WHT	Talya tray was a special choice of women for an experimentation to useful tree	Soil improvement methods (Mulching, Compost, EM)	Animal Draft Zero-Tillage	Cistern
5th selected WHT				Recharge well

A methodology to select, in collaboration with stakeholders, some WHT for test implementation was developed and implemented. This methodology first established some criteria by which the WHT would be ranked. These criteria included economic, ecologic and socio-cultural criteria to make sure that all relevant aspects were considered. The different WHT were then analysed and ranked by the stakeholders, and the WHT with highest rank were selected for test implementation. Using this methodology, several WHT were selected for testing during stakeholder workshops in all study sites (Table 4).

A Choice Experiment (CE) was also performed, with the main aims to validate the selection procedure for WHT in stakeholder workshops, and to provide input data for modelling. Choice experiments elicit preferences for each of the alternatives (in this case water harvesting technologies) in a choice set, where several alternatives are characterised by different attributes (criteria) and their levels. In order to obtain these preferences, a respondent is presented with a series of choice sets of the available alternatives along with the attributes that characterise them.

The results of the CE showed that in the most arid environments (Ethiopia and Tunisia), predominant weight is given to risk reduction, particularly in Tunisia where willingness to pay (WTP) for increased yield is negligible. In contrast, in more sub-humid environments (Burkina Faso and Zambia), farmers are primarily concerned with the yield increase potential of WHT rather than risk reduction.

Overall, the CE results across study sites showed that farmers have a positive WTP for yield and to lower the risk of crop failure. These factors are therefore found to be important in farmers' selection of WHTs and in their application.

2.5 WHT monitoring & results

Selected WHT were, as far as was needed, adapted to optimally suit the local circumstances in the different study sites. The WHT were then implemented, and have been monitored for 2-3 years to assess their effectiveness in harvesting water, decreasing degradation and improving crop yields. Thus, the work in monitoring involved:

- Design and adaptation of selected WH technologies with stakeholders;
- Participatory monitoring and evaluation of the performance of selected WH technologies under different biophysical conditions;
- Assessment of synergies with and impact on existing farming systems and environmental services.

To facilitate the monitoring process a monitoring protocol was developed which included the following: (a) type of WHT, (b) economic, social and environmental considerations, (c) parameters to be monitored including frequency, and (d) scale of application, etc. Every study site has adapted the commonly developed protocol, with some modifications, to suit their specific sites.

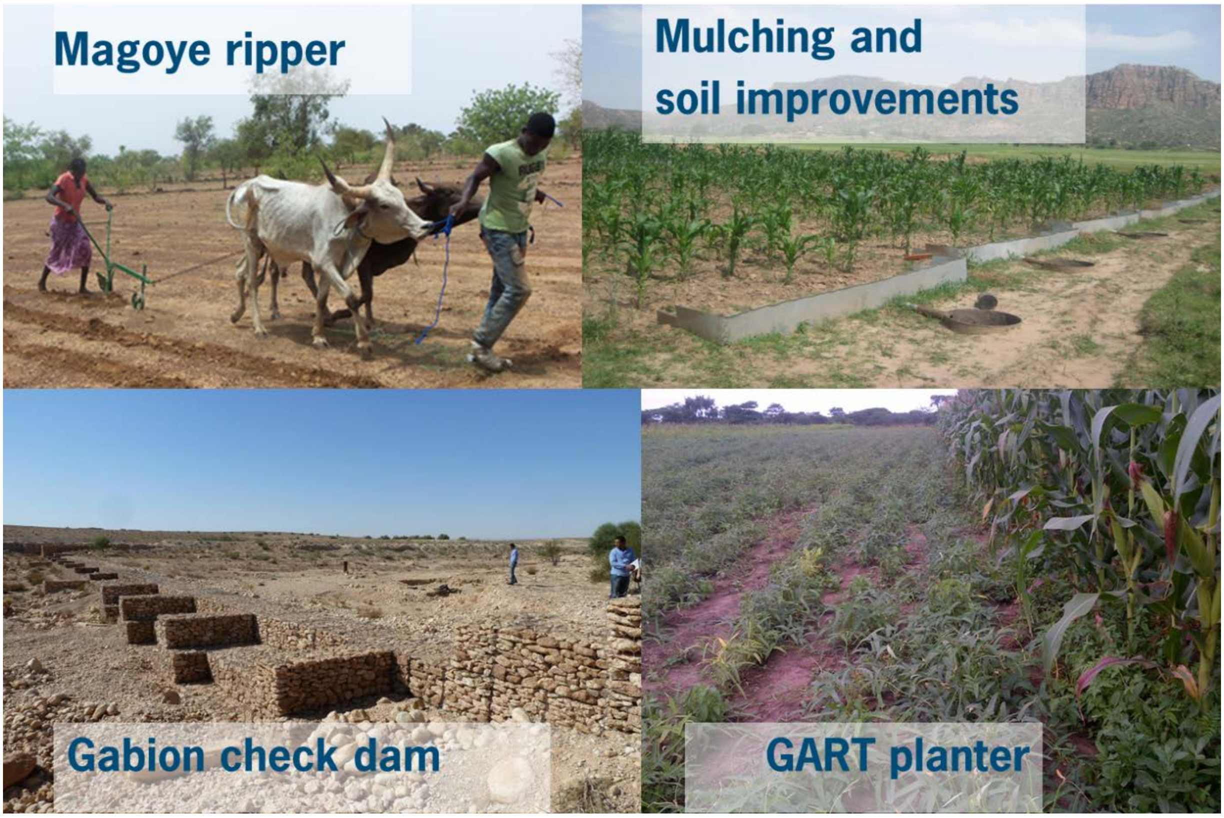

Figure 5. Examples of WHT implemented in the study sites. Top left: Magoye ripper in Burkina Faso; Top right: soil improvement in Ethiopia; Bottom left: WAHARA research at pre-existing check dam in Tunisia; Bottom right: GART planter in Zambia

The adaptation and performance of the different WHT were tested in the four countries of Africa: (a) Tabia, Jessour, Recharge wells, Zai, Gabion check-dams, and Cisterns in Tunisia, (b) Zaï (with compost manure plus microdosing), Magoye ripper, and stone line in Burkina Faso, (c) Percolation ponds with hand-dug wells, Check-dams, bench terraces with hillside cisterns, and Soil improvement (like mulching, and effective micro-organisms) in Ethiopia, and (d) Zero tillage, Strip tillage, and Ripping in Zambia. Figure 5 shows some of these WHT.

Below, 2 more detailed examples of monitoring experiments and their results are given.

Example 1: Burkina Faso; comparison of WHT

Two local WHT (stones bunds and Zaï) were compared to a New WHT (Magoye from Zambia). The control did not include application of fertilisation, because if farmers apply fertiliser, they also used a WHT technique. According to the farmers, the reason for this is that without WHT the fertiliser that is applied simply flows away when there is runoff. Hence, the control and treatments used give the best representation of the options that are used by farmers in reality.

Treatments.
T0= Control= no WHT, no fertilization
T1= stones bunds + 5 tons of compost manure+ microdosing
T2= Zaï + 5 tons of compost manure+ microdosing
T3= Magoye + 5 tons of compost manure+ microdosing

Number of replications: 3 sites, with 10 farmers for each site

The data collected include:

- Dates of rains during the rainy season,
- Dates of ploughing, sowing, weeding, manure application, chemical fertilizer application, pesticide application, harvest,
- Evaluation of yield of grain and straw,
- Soil sample: before sowing, at harvest.

Table 5 gives the yields that were obtained with the different WHT, obtained in one of the 3 sites.

Table 5. Results for one of the sites (Ziga)

	T0	**T1**	**T2**	**T3**
Grain (Kg/ha)	471	742	1036	773
Straw (Kg/ha)	2791	4258	5138	4778

These data show that application of WHT, with application of fertiliser, resulted in an increased of grain yield between 57% and 120% compared to the control. As this experiment reflects how cropping systems are applied in reality in Burkina Faso, these results are considered representative.

Example 2: Zambia

Monitoring of the WHTs started during the 2013/14 farming season and the following data has been collected:

- Soil properties of the soil; soil pH, soil texture, S.O.M, soil respiration, bulk density and soil water infiltration rate,
- Economic data: production costs (labour input, weeding, fertilizer and seed inputs, harvesting costs and transportation costs), and yield data,
- Timing of operations: land preparation, planting, weeding and harvesting,
- Rainfall data: days of rainfall and amounts (mm).

Monitoring was done for two years. Figure 6 shows some aspects of the experiments, while figure 7 shows the yields that were obtained.

Figure 6. Results of the adaptation: (left) maize crop in the zero till field, and (right) maize from the WHT Plot bagged separate from the main crop.

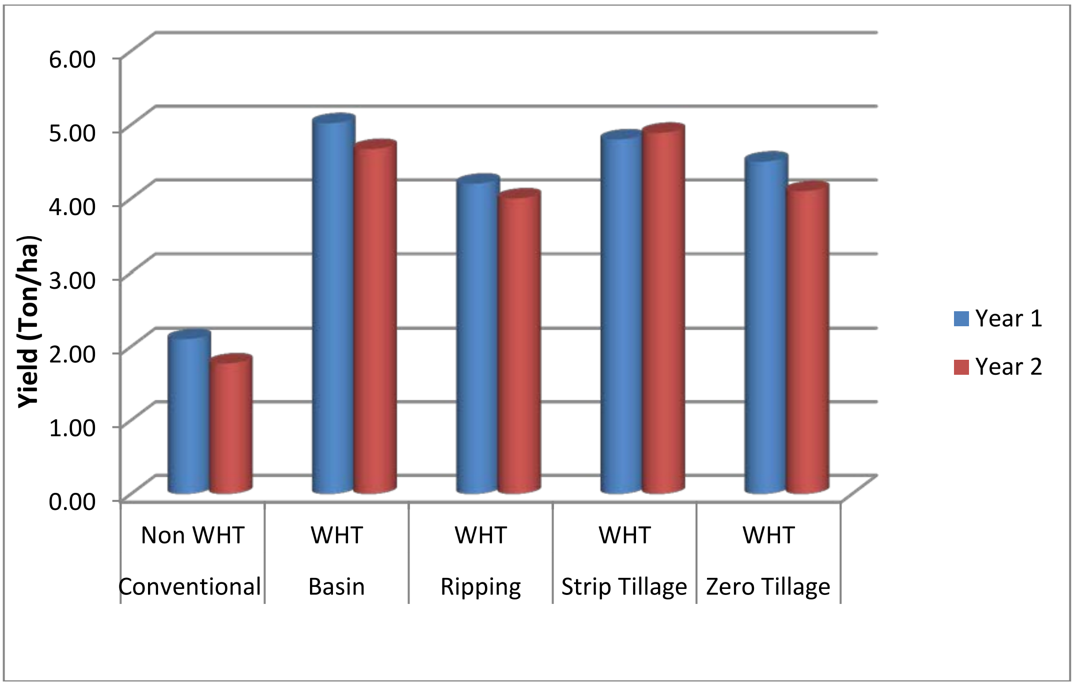

Figure 7. Maize yield with respect to the different water harvesting implemented in Zambia.

Figure 7 shows that for all WHT, maize yields have at least doubled compared to the conventional cropping system, for both years. Generally all treatments recorded lower yields in the second year of monitoring (2014/15 Farming Season) except for WHT Strip Tillage which showed a marginal increase in yield by 1.88%. The reduction in yield could be attributed to the poor rainfall recorded in the second year. The reduction in yield in the WHTs was minimal compared to the conventional method (Non WHT) which, in the second year, recorded yields that were about 16% lower than in the first year. This is because of the water and soil conservation measures employed in the WHTs which enabled the crop to withstand long dry spells experienced during the second year of monitoring.

Crop damage due to poor rainfall (low rainfall) in the 2014/15 farming season was as high as 80 percent in some parts of Southern Zambia (Zambia National Farmers' Union., 2015). The Ministry of Agriculture and Livestock (MAL) reported that national maize (*Zea mays*) production had fallen by 18 percent in 2015 due to low rainfall and drought in some instance (MAL, 2015). This shows that WHT not only increased yields by a factor of more than two, but that it also decreased the consequences of drought.

Monitoring results can be summarised for all sites as follows:

1. Tunisia: (a) Jessour and Tabias played significant role in ensuring crop production but recourse to supplemental irrigation will be needed in case of prolonged droughts, (b) Combined Zai with Jessour/Tabia helped the installation of young trees, and (c) Recharge structures have a positive impact on groundwater replenishment but accumulation of silt can reduce significantly this effect.
2. Burkina Faso: (a) Zaï with compost manure + microdosing is found to be the best technology to enhance productivity, (b) the introduced Magoye ripper gave significant results on grain yield compared to control and stones bunds, (c) Cowpea experiment was well appreciated by the women for its better productivity, and (d) runoff water harvesting using Banka coupled with improved seed variety and proper soil management resulted in an increase in grain yield by three fold. This shows the high potential for enhancing productivity through the integration of proper water harvesting, crop variety and land/soil management.
3. Ethiopia: (a) The introduced bench terraces are among the highly accepted technologies used for creating new cultivable land and enhancing food security as well as reducing erosion. if integrated with any sources of water, (b) Check-dams are found to have great contribution in a number of ways: reducing gully erosion, enhancing groundwater recharge, and storing sediments and buffering moisture/enhancing moisture availability at landscapes, and (d) Soil improvement with Effective Micro-organisms (EM) as well as other amendments have proved to have a good potential for enhancing productivity as these methods would increase soil moisture in soils and enhance soil nutrient. Integrated, landscape level of intervention with different technologies along the landscape (trenches, bench terraces, check-dams, afforestation) has improved groundwater availability (from dry to water level up to 3m below surface) and created a landscape which is resilient to rainfall variability. This is demonstrated by the fact that despite the El-Niño which occurred in northern Ethiopia in 2015, water availability is ensured and productivity has not declined in the watershed because of the landscape level of interventions linked with WAHARA research.
4. Zambia: (a) Implementation of WHT is found to be one of the best options to overcome dry spell and enhance productivity, and (b) SWC measures employed enabled to enhance agricultural productivity.

In conclusion, the implementation of locally adaptive and appropriate WHT is found to address the challenges posed by rainfall variability/climate change. There is therefore a need to upscale the technologies and approaches implemented under WAHARA project.

2.6 Upscaling and Integration

Different aspects of upscaling and integration were studied in three basic ways:

1. Modelling was used to investigate what would happen if WHT was applied to a larger area than just the test plots, and to see what the effects might be of changes like population growth or climate change
2. The conditions under which WHT work were investigated by comparing the results of the 4 sites, and by drawing more general lessons about the scope of WHT in Africa from that
3. The conditions under which WHT spread were also investigated; focussing on socio-economic aspects like the ways in which knowledge about WHT is diffused, and what this means for dissemination of WAHARA project results

These three aspects are discussed in more detail below.

Modelling

For the WAHARA project, the pre-existing PESERA and DESMICE models have been adapted and partially integrated. The fundamental concept that underlies this integration is a calculation, performed for each cell and each plausible combination of crop and management strategies, of the expected net income from the land. This is calculated from the relationship:

Net present value (€/Ha) = Crop price (€/T) x Yield (T/Ha) – Management Costs (€/Ha)

Where:

- Crop price is a function of the chosen crop and the assumed market price for that crop
- Yield is the maximum expected yield for chosen crop x Physical suitability (%)/100
- Management costs are derived from:
    - Routine tillage and other agronomic operations
    - Construction cost of the WHT (averaged over its economic life)
    - Fertiliser/ manure additions
    - Sacrifice of land area for implementing WHT technology

A key strategy to deliver synergies between the two models is through generating suitability maps of PESERA output variables after a single base-line run of the PESERA model, using existing land use and management patterns. This minimizes the need for consecutive feeding in of outputs from PESERA and DESMICE components back to each other. After running PESERA in equilibrium mode to initialize, the model is run in time-series mode. The time series approach allows repeated realisations of the climate to be generated from the frequency distribution of observed data, thus generating suitability curves for the range of expected inter-annual variability. This approach has the potential to respond explicitly to future climate scenarios. The envelope of potential biomass growth is derived from the modelling of repeated realisations delivering suitability maps of e.g. biomass yield and runoff. DESMICE combines these physical suitabilities with estimated farm-gate prices and costs of modifying current management as the basis for assessing yields and net present value, taking account of the averaged risk of crop failure.

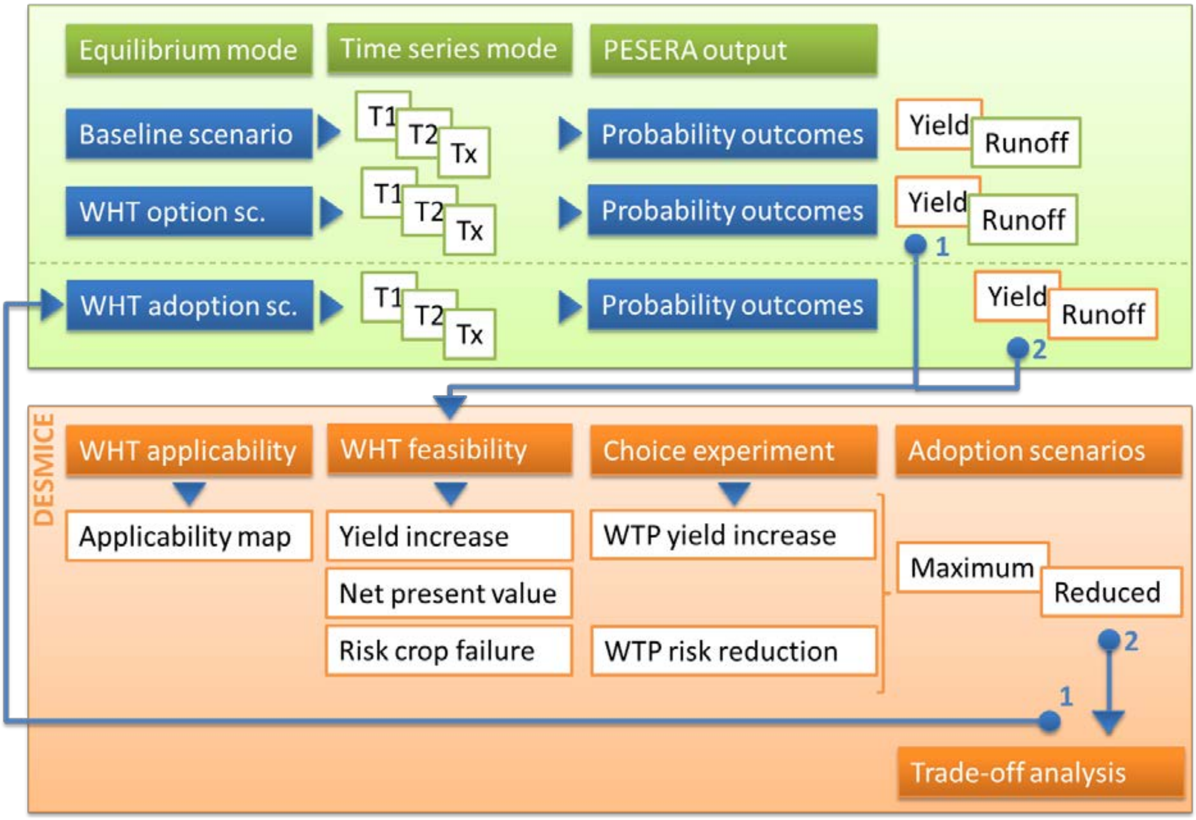

Figure 8. Conceptual diagram of PESERA-DESMICE integration for assessment of WHT technologies. The blue arrows numbered 1 and 2 refer to the two cycles of implementation of the PESERA and the DESMICE models.

Integration between PESERA and DESMICE is implemented in two cycles (Figure 8). In the initial implementation cycle, PESERA and DESMICE are run without consideration of downstream effects of implementing a WHT option, so that it represents a cell-based assessment of WHT potential. In the second implementation cycle, analyses will aim at explicitly considering interactions between cells by accounting run-off flows, allowing estimation of trade-offs between up- and downstream areas to be assessed and a social cost-benefit analysis to be performed for the study area being simulated.

Two types of modification were implemented in the PESERA model, in order to achieve better integration with the conceptual approach of the DESMICE model. The first of these was to incorporate a series of physical suitability estimates, which were incorporated into the combined model to assess the best combination of land use and management choices in terms of their net present value, taking account of physical suitability, market value of the crop and costs in implementing any change in management practices. The second series of changes was to make some estimate of how changes in one cell will impact on downstream sites, principally by making greater or lesser demands on available water for agriculture. This involves routing of flood waters from cell to cell through the network.

The existing DESMICE model has been extended to take into account other factors influencing decision-making, informed by the results of the choice experiment. The choice experiment undertaken in all four study sites tested farmer's preferences for investing time and money in WHT to reduce risk of crop failure and/or increase level of crop production. Preferences for different possible levels of crop failure and yield improvement relating to dry, average or wet years were tested in combination to different levels of investment cost (Dave and Fleskens, 2015). Respondents of the choice experiments needed to consider trade-offs between investment cost, yield level and risk of crop failure. This reflects real-world trade-offs, where investments in WHT might not improve yields during normal-wet years, but on the other hand might reduce risk of (total) crop failure in dry years.

Whereas a WHT may lead to a higher level of crop production in years of sufficient rainfall, a land user may only be interested in investing in the technology if the technology also reduces crop failure in less favourable years. A land user may even be interested in investing in WHT with no expected yield increase if a reduction in risk is achieved. Financial cost-benefit analysis as undertaken in the existing DESMICE model is based on average yield and therefore does not take risk reduction into account. PESERA-DESMICE can be run for different conditions, including for dry years and without WHT, to define risk as the chance that yield is below a certain level. However, the preference for reducing risk of crop failure cannot be determined by the model. Therefore data from the choice experiment is used to construct willingness to pay (WTP) graphs for reduced risk of crop failure (Figure 9).

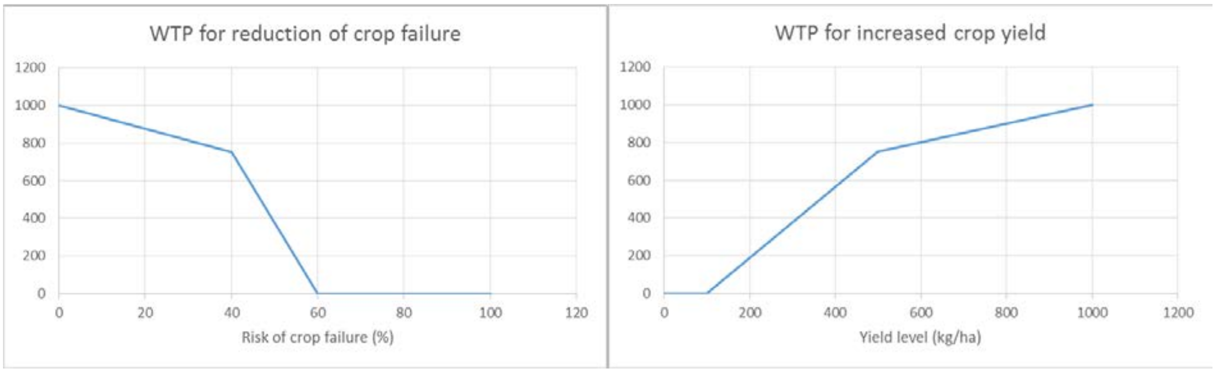

Figure 9. Land user's willingness to pay (WTP) for reduced risk of crop failure and increased crop yield. WTP is given in USD per year.

PESERA model calculations deliver average yield and probabilities of reaching yield levels under conditions with and without a WHT under scrutiny, whereby the probabilities are calculated by running PESERA in time-series mode with different climate realizations. Based on yield level and probability of not reaching a certain yield level threshold, suitability for growing different crops can be determined. DESMICE can then assume that the most suitable crop is grown, which in a situation with WHT might be a different, higher return crop than without WHT. Investment costs for implementing WHT are considered in function of environmental conditions and distance to markets (Fleskens et al., 2014). For financial CBA, the benefit derived from the net difference in average yields multiplied with crop price (and annual maintenance and production costs, where these change as a result of implementing WHT) is considered and discounting applied over the economic life of the technology.

PESERA and DESMICE were used in combination to assess the potential effects of applying WHT at larger scale, and to study the effects of different scenarios regarding e.g. climate change, policies and demographics.

The scenarios considered were:

1. Baseline scenario, in which the agricultural productivity of existing farming systems was simulated for each case study area.
2. Technology scenario, in which the potential for raising agricultural productivity was assessed for each of the WHTs considered.
3. Time series scenario, which allowed to assess agricultural productivity and reduction of the risk of crop failure to be considered together and assessed in relation to farmers' WTP.
4. Study site-specific scenario, in which specific aspects were considered for each study site, such as combined suitability of a catchment WHT approach in Ethiopia and effect of WHT on labour productivity in Zambia.

Example 1: Baseline and zai WHT scenario Burkina Faso

The most important cost related to zai is the digging of the holes, which is laborious in the hard soils. Labour input, agricultural tools and fertiliser are respectively valued at 120, 97, and 100 US$ per hectare. Once constructed, zai can be used for 3 years, after which they need to be re-dug, usually in other parts of the field to gradually improve soil fertility. Box 1 gives an overview of the main assumptions made in order to simulate the financial viability of zai pits. Figure 10 presents the yield of sorghum obtained with and without zai, and the net present value of investing in zai. Baseline yields are very low and range from <275 to 576 kg ha^{-1}. With zai, and using fertiliser, a significantly higher yield range is simulated (775 – 1438 kg ha^{-1}). Due to this significant yield increase, zai are assessed as being financially viable in the study area as can be witnessed from positive NPV.

Box 1. Assumptions used in the simulation of the effects of zai pits.

Assumptions:

- Investment $317
- Economic life 3 years
- Harvest index 17-26%
- Sorghum price $0.25/kg
- Straw price $0.05/kg
- Maintenance $115
- Discount rate 10%

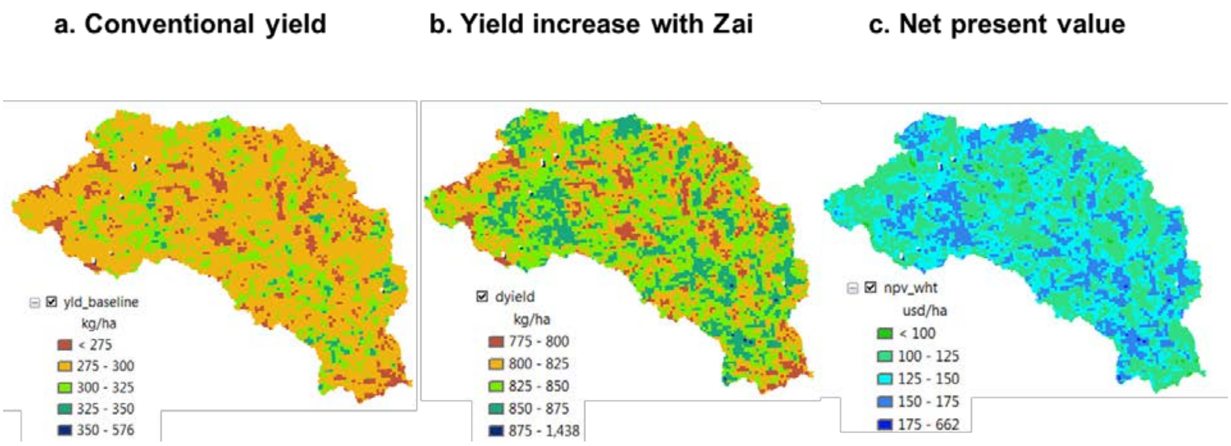

Figure 10. Yield effects and financial viability of zai in NW Burkina Faso.

Example 2: Time series scenarios for WHT in Burkina Faso and Zambia.

The different probabilities of yield being exceeded were simulated and plotted for different technologies and baseline scenarios (Figure 11). All technologies were able to significantly increase productivity levels. Time series analyses confirm this finding (Figure 11a and b), but also indicate that the potential for WH technologies to stabilise high yields is quite variable. A comparison was made between the predicted yield increase at probability p=0.5 between baseline and WHT scenarios. The additional simulated harvest was then compared with the willingness to pay (WTP) estimate elicited from the choice experiment. Table 6 presents the results of this comparison. The choice experiment did not find a notable WTP for reduced risk of crop failure in Burkina Faso and Zambia although actual risk of crop failure without WH is high in Burkina. The WTP for yield increase seems however quite well in line with the investment cost for the WH technology.

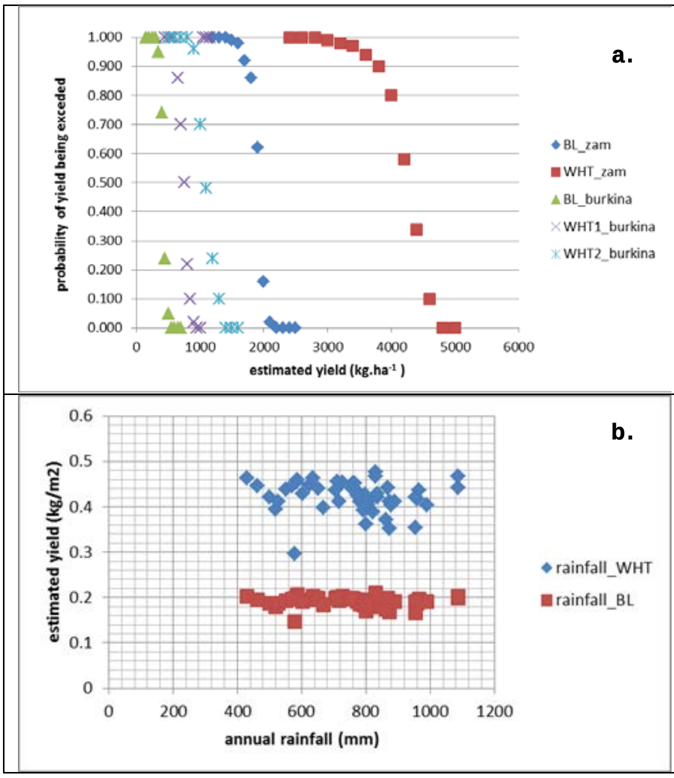

Figure 11. a. Probability of yield levels under different scenarios; b. time series analyses for Zambia; c. time series analysis for Burkina Faso.
Burkina Faso
BL = Baseline
WHT1 = stone bunds and manure
WHT2 = stone bunds, zai and manure
Zambia
BL = Baseline
WHT = Magoye ripper

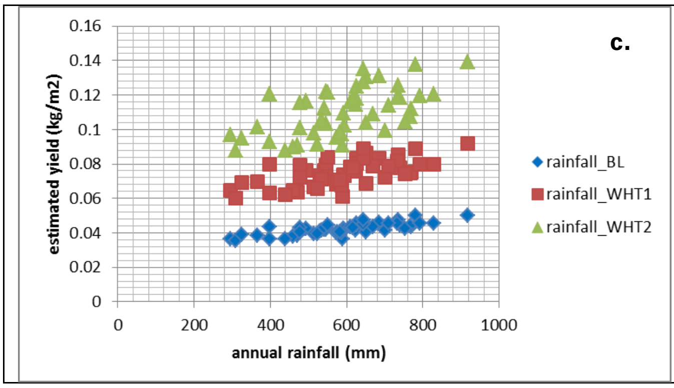

Table 6

	Burkina Faso			Zambia	
	Baseline	Stone bunds	Stone bunds + Zai	Baseline	Magoye ripper
Mean production (kg/ha)	425	750	1100	3800	4200
CE current production* and WHT reference level (kg/ha)	642	n.a.	1300	2497	4000
CE WTP (US$ per kg)			0.71		0.45
WTP for yield increase (US$/ha)		232	482		181
Investment cost (US$/ha)			317		130

*Average of respondents choice experiment

Integration

Results from all different stages of the project were compared for all 4 study sites, and the scope for WHT as defined early on in the project was revisited taking these results from the study sites into account.

As confirmed by the results from the study sites and the various work done under WAHARA Work Packages 1-4, as well as by the experience of others; the water harvesting technologies not only work but have great potential; there is a WH technology in principle suitable to boost water supply issue in rainfed agriculture in most of Africa. And, the expertise to actually do this is in principle available too.

However, while the concept of WH, retaining runoff for productive use, is universal and simple, making it work isn’t necessarily too. It requires adjusting to conditions that cannot be changed while making smart adjustments among those that can be. However, the bio-physical and socio-economic conditions are numerous, interconnected, often conflicting, and they differ widely between locations, even at short distance, as well as over short and long spaces of time. At field level, the working conditions are usually highly variable, so more often than not *unique*. Moreover, the real adaptation challenge is not to make a WH technology *work* under new conditions but to make it *worthwhile*; the expected benefits must be realised with limited resources, without taking a lot of time and for enough people. It adds to the complexity of practical WH adaptation. Table 7 shows which factors should be considered when adapting WHT.

Table 7. Conditions for water harvesting adaptation

Aspects determining the adaptability of the WH technology

Category	Aspects facilitating WH technology adaptation	Aspects that can be changed	To accommodate for what
Design of the WH technology	Already existing WH structures and available WH expertise (to build, use and maintain WH systems) Concept is suitable for a wide range of biophysical and socio-economic environments Simplicity of the design makes it easier to adjust; indicators of simplicity of the design: • All who need to understand it do understand • The design is not complicated more than necessary • It doesn't require a high level or high variety of skills • It requires (mainly) locally available skills, manpower, tools and materials • It can be made quickly • It can be easily expanded and replicated (e.g. modular design) • It is easy to add new things or to integrate other technologies Reasonable financial costs make technical adjustments feasible; consider: Investments, variable and labour costs (including for maintenance), payback amount, payback time during construction/use/alterations	Particular specifications: • Dimensions • Choice of materials • Order of construction in time • Design alterations/choice of design options Know-how: • Understanding and skills of local stakeholders to implement WH	• Required WH capacity; the envisaged volumes of water that can effectively be harvested, transported and stored • Application level; integration of complementary farming technologies (e.g. irrigation, mechanisation, modern farm inputs, high-value agricultural commodities), other water uses than farming, more and other beneficiaries • Other aims/benefits • Financial costs; capital investments, running costs at each phase of development of the WH technology (design, construction, use) • The limitations and opportunities of the working environment

Aspects determining the adaptability of the working environment

Category	Aspects facilitating WH technology adaptation	Aspects that can be changed	To accommodate for what
Climate	Knowledge about the key climate conditions and their trends help establish: • Best overall design, including choice of alternative options • Design specifications	Climate cannot be changed (unless by long-term mitigation on a global scale, which is outside the scope of WH adaptation)	Not applicable
Land	Effective runoff from WH catchment area Knowledge about the key topographic, soil and geological conditions help establish: • Location • Best overall design, including choice of alternative options • Design specifications	Surface - slope (terracing), topography (afforestation, de-stumping and cleaning surface to become more suitable for desired farming systems) Soil - structure, organic matter content, coverage, nutrient content (reduced/zero tillage, mulching, conservation farming, integrated soil fertility management) Rock bed - unpractical to change	Create room for WH technology Make WH technology (more) effective and efficient by: Adjusting for run-off intensity Making land (more) suitable for rain water catchment Making land (more) accessible/suitable for farming Increasing infiltration rate and water holding capacity of the soil Increasing productivity of the soil

Table 7. Conditions for water harvesting adaptation (continued)

Aspects determining the adaptability of the working environment (continued)

Category	Aspects facilitating WH technology adaptation	Aspects that can be changed	To accommodate for what
Natural environment (other than Climate and Land)	Ecosystem services: • Adequate amounts and quality of local building materials make WH construction and adaptation easier • Agricultural potential of the natural environment that justifies investing in WH and WH changes	Optimise maintenance, build resilience, and expand ecosystem service delivery: • Water reserved for natural vegetation and wildlife • Pollution; limit and control • Protect against (excessive) mining of the environment (i.e. extraction larger than natural regrowth) • Space reserved for natural vegetation and wildlife; size, location, quality, access Use of ecosystem services: • Knowledge; strengthen, document, use • New ecosystem services; introduce, exploit	• A broad natural sustainability base for the preferred WH system and changes • Better chances for successful and efficient implementation and maintenance of the WH system and changes
Agricultural system	Individual rather than communal farming practices can make integration of a WH technology into the farming system less complicated Productive farm assets and methods may help the WH technology to be financially or economically more feasible, hence justify certain adaptation efforts Synergies between different components of the agricultural system (e.g. livestock for manure, draft power for soil tillage)	Farming skills training, research, extension and information services Farm enterprise annual crops, trees, livestock, aquaculture, forestry Commodities crop type and variety, livestock/fish breeds Production units - fields number, shape, length and width, fencing Mechanisation level manual, animal draft power, motorised Irrigation have it - yes or no, adjust it - type, size	Productive farming assets make the WH technology (more) compatible and financially and economically feasible Match production unit size to water catchment capacity Adapt production unit shape to make the WH technology more effective/efficient
Socio-economic environment (other than Agricultural system)	Trade-offs, income, food and nutrition security, spin-offs in employment, skills, economic and social development, education, health, community strength and stability, cultural pride Necessary technical know-how and experience available for implementation, community organisation, financial management, use, maintenance	Acceptance Sensitization; information, testimonies, exposure, demonstration Participatory planning Use of local capacities; labour, skills, input supply, other services Alternative uses of the WH technology for other beneficiaries; introduce/add/improve Capacity building Skills at each phase (design, construction, use) for technical know-how, management, facilitation (community organisation, governance), use and maintenance Labour force, tools and equipment, building materials Enhancing overall benefits Productivity and sustainability of rainfed farming (introduce/reorient/improve) Statutory land tenure; introduce, reinforce Services for marketing, farm input supply, training, information, financing, risk reduction (insurance) Multiple uses for WH technologies; introduce/add, make more effective, efficient	A more flexible or diverse use of the WH system and larger community acceptance, participation and know-how will facilitate decision taking, increase local ownership and local participation, and improve the likelihood for a WH technology to be effective and sustainable Enhancing complementary services for greater farm productivity and income can help justify the additional costs of a WH technology

So, modifying a WH technology's design and/or its working conditions to produce an acceptable result within the accessible means can be an intricate balancing act. It explains why WH doesn't spread easily, with an abundance of clearly working examples around for such a long time. At the same time this underlines the importance of adaptation in WH outscaling projects; there can be no adoption without adaptation. It also implies that there is no *precise* WH adaptation working model for *general* use.

To realize the vast scope of WH in African rainfed agriculture, we need to use a general working approach and the capacity to fine-tune it on a case by case basis. The principle of such an approach should be to thoroughly understand and apply WH *principles* inspired by successes from elsewhere rather than trying to use these examples as *blueprints*. It entails an iterative process of observation and learning from what works, to comprehend the underlying conditions of the WH example and the target situation, as well as a pragmatic implementation capacity.

In such an approach, careful monitoring and evaluation of the results at any stage and feedback for the next step -or to improve the last- will be essential. It requires the capacity to integrate local knowledge with insights from elsewhere and an allowance for a not too long but long enough learning curve as well as the stakeholders' willingness to learn and their long-term commitment. More than many other technologies, WH affects the community, even if limited to individual farms. Family farming in Africa is very much embedded in and depending on strong communal customs and traditional rules. Introduction of WH can be drastic enough a change, hence run into obstacles raised by the community despite all good intentions. This has implications for the way WH is being introduced.
Introducing a new WH technology must demonstrate direct economic sense locally (if not instant rewards then at least immediately an outlook for these in the not too distant future). Critical for sustained economic success are policy support, local ownership, local skills and inputs, access to adequate finance, profitable markets, private sector involvement and availability of services as well as professional farmers who can make the WH investments profitable.

To farm successfully, one must be an innovator, certainly when to survive under straining conditions, so always with the pressure to stay productive. Farmers' innovations are testimonies of success, even if they are small changes making use of local opportunities such as local materials and natural features (costing little money) and preferably are simple too (costing little time and effort). An adaptation strategy should bank on such farmers for their creative capacity to innovate and solve problems and see opportunities. However, they cannot do it without having ownership of productive resources and access to a range of farmer services.

Dissemination, learning and adoption

The WAHARA project aimed to contribute to a better understanding of the possibilities presented by Water Harvesting by identifying and field-testing promising technologies; assessing the potential of their biophysical, socio-economic and political uptake; and outlining a strategy to promote their scaling-up. While the research project's activities are located in four countries-- Tunisia, Ethiopia, Zambia and Burkina Faso-- the findings and deliverables are pertinent to the broader context of Africa. This has been ensured through the choice of research questions and design of the research methodology.

WAHARA analysed the options and enabling conditions for the spread of WHTs in Africa by identifying key WHTs in each of the four countries and tracing the pathways of their spread. It identified good ideas and bad ideas, effective interventions and unsuccessful projects, various stakeholders and their roles. The picture that emerges reveals upscaling as a multi-level process that takes place horizontally (geographical spreading among one stakeholder group), as wells as vertically (spreading across various levels of stakeholder groups). WAHARA research also highlights that the process of upscaling of WHTs is often not driven by governments or NGOs who consider it their responsibility to do extension unto farmers, but unfolds organically through the agency of farmers who constantly try to innovate in an effort to increase their productivity.

Based on this analysis, WAHARA produced a vision for water harvesting in Africa, which is available from the WAHARA website. Some main points from this vision are given below.

In the context of WHTs, upscaling in general refers to achieving their increased diffusion and implementation. The end objective is on-the-ground implementation over a large area by a large number of land users. There are different routes to take concerning upscaling.

Uptake among a large number of land users over a large area (visualized as 'horizontal' upscaling) also requires uptake across a large number of stakeholders operating in the agriculture and water sectors such as NGOs, extension workers, private companies, etc. (visualized as 'vertical' upscaling) (figure 12). Horizontal upscaling—or geographical spreading of WHT— has limits which vertical upscaling helps it cross over and go beyond. An example is the spread of Zai pits in Burkina Faso through farmer-to-farmer learning. Impressive as it is, it is confined to the northern part of the country. However, over the years there has been a massive uptake of the technology among government agencies and NGOs. They are now trying to adapt it and spread it among farmers in the South as well.

Those concerned with upscaling of WHTs would do well to recognize that the process can be driven in several different ways by several different actors. So while the government played the central role in large-scale Soil and Water Conservation efforts in Ethiopia, the spread of Zai Pits in northern Burkina Faso was down to some motivated farmers taking the initiative to experiment with the ancient technique and teaching their neighbouring farmers. In Zambia, Conservation Farming was introduced by the private sector agro-businesses, who continue to spread it among smallholder farmers who supply them cotton and maize. The Zambian and Burkina examples show how upscaling of WHTs need not always be an planned intervention, but an organic process that unfolds through the agency of farmers. In such cases, upscaling requires recognising these processes and facilitating them.

Figure 12: Upscaling: upscaling is a multi-level process that takes place horizontally (geographical spreading among one stakeholder group), as wells as vertically (spreading across various levels of stakeholder groups)

Based on research carried out in Ethiopia, Zambia, Burkina Faso, and Tunisia an analysis was made of the options and enabling conditions for the spread of WHTs in Africa by identifying key WHTs in each country and tracing the pathways of their spread. Options and enabling conditions can be classified as pertaining to one of six key areas: Governance, Participation of Stakeholders, Attitudes and Behaviour, Technology, Communication, and Education.

It is a cliché expression, but the core ideas extracted from experiences in Tunisia, Ethiopia, Zambia, and Burkina Faso point to one thing: what works is putting the farmer at the centre of it all, respecting his agency, treating him as a client rather than a beneficiary. The spread of WHTs among farmers should essentially be a process of pitching WHTs to them. When farmers are convinced about their benefits to productivity and income, they will take them up, innovate and adapt them to their specific needs. That's when WHTs truly spread. This core process can be supported by securing farmers' land rights, building trust, facilitating farmer-to-farmer learning systems and linking them with formal education & research systems. All this requires investments, and it is essential that there is willingness to make those investments. The evidence base of the impact and potential of WHTs is robust. The need of the hour is to translate it into investments, by reaching it out to more and more farmers, governments, NGOs, students, academics and getting their buy-in.

3. **WAHARA potential impact**

Water harvesting holds considerable promise to increase water use efficiency and agricultural productivity while sustaining ecosystem services, and to contribute to developing vigorous and resilient agricultural economies. The expected impacts of WAHARA were:

i) improving the livelihoods of rural communities by designing and implementing innovative appropriate water management technologies applicable in a wide range of hydrological, agro-ecological and socio-economic conditions of rainfed Africa.
ii) strengthening the potential and sustainability of rainfed agriculture by increasing food production and security. These impacts will operate on three fronts feeding into each other: knowledge impact by integrating traditional and scientific knowledge, land development impact through strengthening the potential, resilience and sustainability of rainfed agriculture in the study sites and upscaling impact by stimulating both horizontal (geographical) scaling up and vertical (from field levels up to decision making arena's) scaling up.

To achieve impact, dissemination is of crucial importance. Therefore, dissemination activities were started early in the lifetime of the project, and have been continued throughout its lifetime, and even after the end of the project. Table 8 gives an overview of dissemination efforts made in WAHARA study sites.

Table 8 Dissemination efforts study sites.

Activities for	**Dissemination efforts study sites**
Practitioners	At least 2 stakeholder workshops in all sites, field days, WAHARA completion meeting, folk theatre in Burkina Faso
Farmer organisations	Took part in stakeholder workshops, field days, other meetings, film in Burkina Faso, WAHARA completion meeting
NGOs	Took part in stakeholder workshops in some sites, actively involved in Ethiopia, presentations at meetings, WAHARA completion meeting
Local – national authorities	Took part in stakeholder workshops in some sites, policy brief in all sites, presentations at meetings, WAHARA completion meeting
Scientists	Some papers published, more expected. Presentations at meetings

Apart from these, WAHARA also disseminated its results at a more general (not study site specific) level. The main efforts that can be mentioned in this regard are:

Videos: A total of 33 videos were produced over the project period. The videos documented the project context and project results in the 4 study sites. They were disseminated online through TheWaterChannel (www.thewaterchannel.tv) where they got a combined 221,740 views (as of March 16, 2016). This mode of outreach was among the demographic that covers water managers, students, academics, and general enthusiasts (based on visitor profile of TheWaterChannel). Offline dissemination of the videos included was carried out by developing a DVD of the documentary 'Land, Water and Livelihoods: The Watershed Movement in Tigray'and disseminating it among key stakeholders in Ethiopia (500 copies). A shortened version of the documentary was broadcast on TV3 in Spain in March, 2012.

Publications: WAHARA collaborated in several publications that describe WHT that could be used in Africa. WAHARA scientists also contributed to the book 'Water Harvesting in Sub-Saharan Africa' edited by William Critchley and John Gowing. Information on WAHARA was also included in the Horizon Magazine and website.

Collaboration with other projects: WAHARA also took part in the FP7 Africa Cluster, which had a focus on collaborating in the field of dissemination. WAHARA for example contributed to a questionnaire on dissemination that was developed by the EUA4FOOD project, and it also contributed to the FP7 Africa film that was made.

International arena: Dissemination at international scale took place among scientists through scientific publications, through dissemination to international policy makers, and through dissemination among the general public through the videos.

Final project event: Finally, a stakeholder meeting was held at the end of the project to inform stakeholders from all 4 study sites about WAHARA results. This meeting was held in Zambia, but stakeholders from Tunisia, Burkina Faso and Ethiopia also attended. For this occasion films were made about WAHARA work in each of the four study sites. The event drew the attention of several media, resulting in publications, radio and television broadcasts about WAHARA in Zambia

By combining the dissemination efforts described above, with the project results that were described in earlier sections of this report, WAHARA contributed to impact. Table 9 describes how WAHARA contributed to achieve the two main impacts listed above: i) improving livelihoods of rural communities by designing and implementing innovative appropriate water management technologies applicable in a wide range of hydrological, agro-ecological and socio-economic conditions of rainfed Africa, and by ii) strengthening the potential and sustainability of rainfed agriculture by increasing food production and security.

Table 9. Expected impacts from the project, project realization and assumptions and external success factors.

Expected impact	**Project realization**	**Assumptions and external success factors**
Knowledge impact		
Integrating approaches	• Overview of WH options and adaptations created and dissemination approach applied and ground truthed in four study sites with local stakeholders • Criteria established for sustainable impact on improving livelihoods with WH technologies	• Active cooperation of farmers, support organizations and investors in each project site • Possibility to express impact in terms of food and water security indicators using integrated biophysical-economic modelling of water harvesting technologies
Existing and new traditional and scientific knowledge on water harvesting combined	• Participatory identification, selection and assessment of water harvesting technologies • Stakeholder knowledge and preferences incorporated in integrated model for impact assessment of water harvesting technologies	• Active cooperation of stakeholders at various levels in workshops for identification, selection and evaluation of water harvesting technologies and guidelines for adaptation
Expanded water harvesting repertoire	• New technologies discussed and tested, based on input from other WAHARA sites. E.g. Magoye ripper (from Zambia) tested in Burkina Faso; zai pits (from Burkina Faso) tested in Tunisia. • All of this captured in guidelines for adaptation of WH technologies to various conditions in rainfed Africa	• Systematic creative engagement of farmers and scientists

Local development impact		
Improved agricultural production	• Water harvesting technologies have the potential to increase rainfed production in all the study sites, monitoring shows that in some cases yield can increase threefold.	• Verification through participatory monitoring and performance evaluation of the WH technologies, including model evaluation. • Successful methods to incorporate technologies in local and in farm practices using most effective dissemination mechanisms
Better drought resilience	• Reduced fall in farm production in drought years compared to normal years, confirmed by results from e.g. Ethiopia and Zambia	• Support for implementation of water harvesting and buffer management measures from main players in the project sites, i.e. land users, regional governments, safety net programs, local banks, regional development programs, NGOs
Improved water security	• Good prospects for the improvement of water security in project sites due to implementation of water harvesting technologies • Criteria and provisions defined affecting the suitability of WH technologies to provide water security to multi-level stakeholders	• Verification through participatory monitoring and model evaluation • Cross-country analysis of impacts on water security and regional development enabled by input from multi-level stakeholders, and support for learning an action strategy
Upscaling impact		
Upstream and downstream effects of WH quantified	• Developed and implemented state-of-the-art GIS-based biophysical and socioeconomic models (Quick Scan Tool, PESERA-DESMICE) to assess the impact of WHT	• Required data are at hand or can be collected in framework of the project • Relative stakeholder preferences for production and risk captured through a Choice Experiment
Biophysical and socioeconomic conditions related to suitability of WH technologies	• Comparative analysis across study sites and other African environments executed shows there is considerable potential for WHT to raise yields and reduce drought risk. Applicability limitations for each WHT were assessed. Combinations of WHT and soil fertility measures (e.g. Burkina Faso) have the highest effect	• Model developed and applicable to evaluate potentials of WH technologies for different African environments • Data for model calibration of the combined effect of WHT and soil fertility management available
Knowledge transfer and adoption of WH technologies spreading across rainfed Africa	• Guidelines for adoption of WH technologies prepared and provided to stakeholders	• Knowledge diffusion and learning through farmer to farmer experiences and extension services

		• Providing enabling conditions for horizontal (geographical) and vertical (from field to decision makers) scaling up

Summarising, the WAHARA project contributed to both i) improving livelihoods and by ii) strengthening the potential and sustainability of rainfed agriculture, as follows:

i. WAHARA monitoring work has, in all sites, shown that yields can be significantly increased due to the use of WHT. For example, in Burkina Faso and Zambia yields on fields with WHT were up to 3 times higher than in the control plots. WAHARA work also showed that WHT provide resilience against the effects of drought. For example, yields were obtained in the Ethiopian study site in 2016 despite the severe droughts that currently occur there. For relatively cheap WHTs (e.g. Magoye ripper) which moreover lead to a saving in labour costs compared to conventional systems (e.g. in tillage operations) the financial return is generally positive. Structural measures are costly to implement and require government support as effects are not all accruing to the land user implementing them. In the case of Ethiopia, crucial for an integrated WHT approach at sub-catchment level is that people taking part in the activities can benefit through increased water availability in the valley bottoms. Also in Ethiopia, the use of bench terraces was found to create job opportunities through the creation of new cultivable land. In the case of Tunisia, some support in the form of subsidies is indispensable to promote upscaling the adoption of WHT.

ii. From the WAHARA results it is clear that WHT can improve food production and food security. This also increases the potential and sustainability of rainfed agriculture and makes it more resilient and better able to cope with the challenges posed by climate change and population dynamics. WAHARA has taken a participatory approach in which traditional and scientific knowledge were integrated, and has stimulated upscaling of WHT by taking an active dissemination approach in collaboration with stakeholders. For example, WAHARA has contributed to the creation of videos on DVD about managing land and water in Ethiopia. These videos have contributed for an increased interest in the use of WHT. Partnerships with stakeholders have been established in all study sites, and in several study sites (formal) contacts have also been established with NGOs working in the area. These networks have been used to spread WAHARA results, and will remain in place after the end of WAHARA. WAHARA has furthermore analysed the conditions under which horizontal and vertical upscaling proceeds in the different study countries, and has used this knowledge for targeted dissemination to a range of stakeholders, including policy makers.

The final impact that WAHARA will have is beyond the control of the project, as it depends on the uptake of WHT by stakeholders in the study sites and their wide regions. In this regard, it can be mentioned that bench terraces have been promoted in the study site in Ethiopia, and that the success of this WHT has been noticed by the Ethiopian government and by other stakeholders. As a result, adoption of bench terraces is now spreading throughout Tigray. Hence, although upscaling of WHT is beyond the WAHARA project, the project has been conducive to such upscaling. As such, the WAHARA results are of use first of all the local farmers in the 4 study sites, but also to their colleagues in neighbouring areas, as well as to various NGOs and government branches who are involved in agriculture, sustainable development, land and water management and related topics.

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Further reading
This document is a summary of WAHARA, based on the reports that were made by WAHARA. All reports are available on the WAHARA website. An overview is given below.

No	Title
1	Activity report period 1
2	WAHARA website (D7.1)
3	Study site database of spatial and non-spatial data (D1.1)
4	Stakeholder workshop report (D1.2)
5	Report on WH inventory, history and success stories (D1.3)
6	Water Harvesting Potential for Africa
7	Water Harvesting Technologies
8	Revue de litterature zone nord-ouest Burkina Faso
9	Revue des technologies au Burkina Faso
10	Report on assessment of the potential for WH (D1.4)
11	Minutes WAHARA meeting Mekelle
12	Minutes WAHARA researcher workshop Wageningen
13	Minutes WAHARA Plenary Meeting Djerba
14	Procedure of Water harvesting technologies evaluation and selection, Oum Zessar watershed

	Tunisia case study
15	Second Workshop Report on Participatory Selection of Water Harvesting Technologies. Study Site: Ethiopia
16	Global compilation of WH technologies (D2.1)
17	Replicable participatory WH selection methodology (D2.2)
18	Selection workshop report (D2.3)
19	Continental scale quick assessment tool (D4.1)
20	Report on Approaches and Experiences of Knowledge Transfer of Technology
21	Meeting notes WAHARA meeting Leeds
22	Determining the saturated vertical hydraulic conductivity of retention basins in the Oum Zessar watershed, Southern Tunisia
23	An integrated PESERA/DESMICE model capable of simulating hydrological and economic impacts, including food and water security, of WH from field to regional scale (D4.2)
24	Report on stakeholder choice validation (D2.4)
25	Farm household agro-socio-economic surveys. A cross-country socioeconomic comparative analysis
26	Farm household agro-socio-economic survey in Ethiopia; analysis report
27	WAHARA meeting Ouagadougou, Burkina Faso
28	Report on Adaptation and Performance of Water Harvesting Technologies in Northern Ethiopia
29	Report on adaptation of water harvesting technologies: Case of the watershed of wadi Oum Zessar, Tunisia
30	Report on Adaptation and Performance of Water Harvesting Technologies (D3.1)
31	Minutes WAHARA meeting Zambia
32	Scenarios: impact of WH under drivers of change (D4.3)
33	Integrative analysis of results from the four countries (D5.1)
34	Report on critical biophysical and socioeconomic conditions for WH adaptation (D5.2)
35	Guidelines on adaptation of WH to different conditions (D5.3), including Report on stakeholder evaluation of adaptation guidelines (D5.4)
36	Final publishable summary
37	Report on options and enabling conditions to achieve spreading of WH (D6.1)
38	A multi-level strategy for scaling-up of WH technologies (D6.2)
39	Policy notes (D6.3)
40	Suite of dissemination products (D6.4)