Food and Agriculture Organization of the United Nations

Strengthening agricultural water efficiency and productivity on the African and global level

Status, performance and scope assessment of water harvesting in Uganda, Burkina Faso and Morocco

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Acronyms and abbreviations

2iE	International Institute for Water and Environmental Engineering
AES	Agricultural Extension System
AEZ	Agro-Ecological Zones
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASDSIP	Agriculture Sector Development Strategy and Investment Plan
AWM	Agriculture Water Management
CCU	Climate Change Unit
FCFA	West African Franc
CILSS	Permanent Interstates Committee for Drought Control in the Sahel
DCS	Directorate for Conservation of Soils
DIAEA	Directorate of Irrigation and Land of Agricultural Area
Dm	Moroccan dirham
DSIP	Development Strategy and Investment Plan
ET	Evapotranspiration
FFS	Farmers Field Schools
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HCEFLCD	High Commission for Water and Forests and Desertification Control
IAV	Agricultural and Veterinary Institute Hassan II
INERA	National Institute of Environment and Agricultural Research
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries

MAPM	Ministry of Agriculture and Fisheries Maritime
MARHASA	Ministry of Agriculture, Water Resources, Sanitation and Food Security
MCA	Multi-Criteria Analyzes
MDCE	Delegate Ministry in charge of Water
MWE	Ministry of Water and Environment
NAADS	National Agriculture Advisory Services
NDP	National Development Plan
NWP	National Water Policy
NGO	Non-governmental Organization
ONCA	National Office of Agricultural Council
OPM	Office of the Prime Minister
PD	Person Days
PMA	Plan for Modernization of Agriculture
SLM	Sustainable Land Management
SSI	Small-scale Irrigation
Ush	Ugandan Shilling
WfP	Water for Production Department
WfAP	Water for Agriculture Production
WH	Water Harvesting
WOCAT	World Overview of Conservation Approaches and Technologies

Introduction

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Managing water harvesting for agriculture and transforming landscapes

Water Harvesting (WH) is best described as the “collection of runoff for its productive use” (Critchley & Siegert. 1991) and can be categorized into two groups: (1) rainwater harvesting: the practice of harvesting runoff from natural surfaces as well as artificial surfaces such as roofs; and (2) floodwater harvesting: the practice of harvesting the discharge from ephemeral watercourses (Critchley, & Siegert. 1991).

There is a vast range of WH techniques available and applicable to various geographical conditions. Productive uses include the provision of domestic and livestock water, the collection of runoff for crops, fodder and tree production, and less commonly water supply for fish and duck ponds (Critchley, & Siegert. 1991). Many WH techniques originate from local agricultural practices, whereas some are introduced from other geographical areas (regions or countries). WH practices are commonly coupled with agronomic and forestry practices such as planting trees, managing soil fertility and enhancing soil water infiltration and retention capacity.

One approach to WH is the concept of water buffering. The idea behind water buffering is to store water when it is plentiful and in turn, to make it available when it is scarce; storage is thus the central element. By integrating small storage structures across the landscape in a planned and systematized manner, it is possible to create a water buffer that helps dealing with water seasonality and drought. Three categories of storage can be distinguished:

1. Groundwater storage
2. Soil moisture storage
3. Surface storage

All solutions can be used as stand-alone measures, but to create an improved water buffer they work at best when integrated with each other with high density and at landscape scale. Such an approach, known as 3R[1] solutions, can be applied in diverse environments: from

[1] 3R stands for "Recharge, Retention and Reuse" of groundwater and rainwater. 3R is an initiative of four Dutch entities (RAIN, Acacia Water, MetaMeta and Aqua for all) that emphasizes the benefit of collecting water, extending the chain of water use and reusing water as much as possible within a basin. More information can be found at: http://bebuffered.com/

arid to humid areas, in hilly areas but also in flat flood plains. If landscapes are transformed at scale, many processes change with it: the hydrology, the sedimentation processes, the microclimate, the soil chemistry and nutrient cycle and the regeneration of vegetation cover. The water stored in the water buffer can be used for multiple purposes such as agriculture, livestock watering and domestic use.

Uganda, Burkina Faso and Morocco, like many other African countries, rely on agriculture as a driving force for their social and economic development. Most smallholder farmers depend on rain-fed agricultural production for their livelihoods. At the same time, irregular and unreliable rainfall is a main contributing factor to low agricultural productivity. Managing the scarce rains is thus crucial to improving food security and livelihoods. In fact, the greatest potential increases in yield are in rain-fed areas where managing water is key (Molden, 2007).

Focus and scope of this assessment

The assessment outlined in this report forms part of the 'Strengthening Agricultural Water Efficiency and Productivity on the African and Global Level' project, which aims at reducing hunger and poverty in three African countries (Burkina Faso, Morocco and Uganda) by focusing on the improvement of AWM and mainstreaming AWM in national frameworks and processes. In particular, this report contributes to Output 3 of the project: Enhanced water harvesting capacity for agriculture in Burkina Faso, Morocco and Uganda.

This assessment targets agricultural water extension agents and technical experts, providing them with clear indications on how to improve WH capacity for agricultural production in the three case study countries, as well as how to select feasible and suited WH techniques for different geographical areas. It is an assessment of the status, performance and scope for improving WH for agriculture in the three countries and provides a portfolio of technologies with their suitability and feasible application to countries' conditions.

This report summaries the assessment of 42 WH best practices across the three case study countries using Multi-Criteria Analysis (MCA). Each of the selected WH techniques is already extensively applied or has potential to be applied in Uganda, Burkina Faso and/or Morocco.

The objectives of the detailed assessment of WH technologies in the three countries are:

- To present a number of WH practices, both already existing in the three countries as well as others implemented in other countries, their main features, benefits and limitations
- To evaluate their performance with respect to several biophysical, technical, and socio-economic criteria
- To guide decisions on the choice of a single or a combination of several WH techniques that show positive impacts on the environment, socio-economic development, and agricultural productivity and profitability.

Understanding the agriculture and water management situation in Uganda, Burkina Faso and Morocco

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Uganda

Climate and Physical Landscape

Uganda is the third largest East African country and lies almost completely in the Nile Basin, sharing boundaries with Democratic Republic of Congo, Kenya, Rwanda, South Sudan and Tanzania. The country is characterized by different landscapes, where several flat-topped mountains dominate the southern hills, disjointed by wide valleys that are generally occupied by swamps.

The country is predominantly characterized by an equatorial climate that shows slight differences in annual rainfall and temperatures. A dry sub-humid climate characterizes 67 percent of the country's topography and 20 percent of the land is categorized as semi-arid. Rainfall in the northeast ranges from 750 mm per annum in Karamoja pastoral areas, to 1500 mm per annum on the mountain ranges and around the shores of Lake Victoria (AQUASTAT, 2015). Southern Uganda experiences considerable rainfall throughout the year where most of the rainfall occurs between March and June and then again between November and December. In the north, towards South Sudan, the climate becomes drier with November to February being the driest months.

The total renewable water resources in Uganda are estimated to be 66 km^3 per year, however, only 0.5 percent of the total renewable water resource is used; this translates into an opportunity to develop water sources for agricultural production. Uganda is endowed with abundant surface water resources totalling up to 43.3 km^3 per year, yet a high spatial difference exists in runoff. The strong variations in seasonal rainfall cause varying stream flow, and the occurrences of moisture shortage in the areas near Lake Victoria are generally in the form of dry spells between December and February and between June and September.

The geological formation in Uganda is one of the oldest in the region and it is overlaid by ferralitic and ferruginous soils (Sabiiti & Teka, 2004). These soils have thin top layers (20–30 cm) and deep subsoil (5–10 m) ranging from clay loam to sandy loam. Clay loam soils are predominant in the moister regions.

Uganda can be divided into four main Agro-Ecological Zones (AEZ):

- **High altitude zone:** characterized by temperate zone crops in some areas of Ankole, Kigezi, Mbale, Sabel, Toro and in West Nile.
- **Pastoral arid to semi-arid zones:** areas that are characterized by pastoral systems and are generally in the East of Ankole, Karamoja and west of Masaka.
- **Northern and eastern short grassland zones:** characterized by mixed farming systems such as, cotton-finger millet and short grassland.
- **Southern and western tall grassland zones:** characterized by mixed farming systems, such as perennial and annual crops and tall grassland.

Agriculture Sector

Uganda's agricultural sector plays a central role in the country, employing approximately 80 percent of the population, which translates to 33 percent of the Ugandan Gross Domestic Product (GDP) (Wanyama, 2014). Despite this, undernourishment is still prevalent and affects 35 percent of the population. The majority of the population is composed by small to medium-scale farmers occupying land with an average area of 2.5 hectares. Undernourishment levels are due to stagnant productivity of the agricultural sector and high dependence on rainfall. When it comes to irrigation practice, the total cultivated area under irrigation is less than 1 percent. In Uganda's Agriculture Sector Development Strategy and Investment Plan (ASDSIP), crop yields at farm level were recorded and compared. Results show that crop yields are far below the achievable potential, thus indicating great opportunities for improvements.

Institutional Set-up

Both, the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and the Ministry of Water and Environment (MWE), promote WH. There are several initiatives such as the construction of rooftop water harvesting and valley dams/tanks, which are directly supported by the Office of the Prime Minister (OPM). Furthermore, institutions such as the Climate Change Unit (CCU) and the Water for Production Department (WfP) of the MWE and Water for Agricultural Production (MAAIF) share similar responsibilities.

The National Water Policy (NWP) (MWLE, 1999) sets a clear guiding objective regarding water for production:

> *'Promote development of water supply for agricultural production in order to modernize agriculture and mitigate effects of climatic variations in rainfed agriculture.'*

The NWP also sets out the specific responsibilities of each line ministry. For example, MAAIF is responsible for planning, advising, supervising and monitoring the management and use of irrigation, fisheries and livestock schemes.

In addition to the NWP, the National Development Plan (NDP) sets the basis for the Agricultural Sector Development Strategy and Investment Plan (DSIP). Water for Agriculture Production (WfAP) is a thematic area under the DSIP with the aim of developing infrastructure for the provision of water to farmers for agricultural production, which includes irrigation, water for livestock and aquaculture. Within the irrigation support component of this thematic area, water harvesting is recognized as a viable method to be promoted in order to enable farmers to practice supplementary irrigation (WfAP, 2012).

Capacity Building and Extension Services

Currently, Uganda's capacity building and extension services for water harvesting to improve agricultural production is mainly provided by three entities: (1) universities and research institutes; (2) agricultural extension systems – National Agriculture Advisory Services (NAADS); and (3) other organizations and networks.

The Ugandan Agricultural Extension System (AES) experienced a drastic reform after a Plan for Modernization of Agriculture (PMA) that led to the establishment of NAADS in 2001. NAADS was established because at the time the public extension services were costly and ineffective. In a bid to improve extension services, NAADS has a decentralized structure, with farmer forums and institutions at district, sub-county and parish and community levels. Nonetheless, NAADS is only partially succeeding to meet its mandate. . Hence, farmers are generally not aware of WH techniques and Soil & Water Conservation (SWC) and they do not know what to do, or how to seek technical support.

Other organizations and networks are active in providing extension services in Uganda. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), formed in 1994 by various national agricultural research institutes of ten member countries, share similar initiatives across member countries to strengthen Africa's capacity. They help to build institutional and human capacity (in agricultural extension and research) and agricultural support services, as well as empowering farmers (ASARECA, 2007). Their idea is to mainstream the importance of WH and other Sustainable Land Management (SLM) approaches to enhance agricultural output in Uganda and the region.

Potential and Needs for Water Harvesting

Uganda has scattered in-situ WH techniques in rain-fed areas. Many local smallholder farmers try to enhance rain-fed production through WH techniques such as, trash-lines, terracing and in-situ WH for banana plantations. Many of these WH techniques indicate that they work well under Ugandan biophysical and socio-economic conditions, showing that they are also well recognized by farmers. Some WH techniques like valley tanks, which have been introduced in pastoralist areas such as Karamoja by NGOs and the government, are now being implemented in other AEZ and there is potential to use them for small-scale irrigation. Similarly, in the mountainous areas, terracing was introduced where communities began to use the technique on sloping land. Due to population pressure and land resources becoming scarcer communities have also begun to adopt some types of terracing in lower areas. However, very little has been done to fully study, document and upscale these techniques across different AEZs.

There are several opportunities and needs with respect to WH when looking at the Ugandan context as a whole, especially regarding awareness raising, capacity building and resource management aspects. There is a need to train government and knowledge institution's personnel about new and country applicable management systems, planning, implementation and techniques on WH. Curriculum and learning materials on WH taught at technical institutes and universities need to be revised and NGO staff need to be trained in order to continuously promote and introduce WH techniques at the local level and sensitize farmers about their benefits on crop production.

A comprehensive communication approach needs to be renewed between the local and national government institutions, with a more harmonized approach among technical support units. At present, much data on WH techniques and their impacts is scattered and fragmented, improving communication and minimizing bureaucracy will be necessary for efficient data collection, storage and dissemination. Such changes will assist in the development of clear procedures for water recharge and retention, as well as national guidelines on how to implement WH techniques, which are much needed.

Burkina Faso

Climate and Physical Landscape

The climate in Burkina Faso is primarily tropical with two main seasons. The dry season is characterized by hot, dry winds coming from the North (Sahara) and the rainy season is characterized by intense rainfall and moist winds blowing from the South. Rainfall varies from the North to South, whereby the Southern parts of the country experience more rainfall. Potential evapotranspiration (ET) also differs from the North to South. In the Sahelian zone, ET can reach as high as 2260 mm per year, whereas in other zones it can reach 1800 mm per year.

Burkina Faso is a relatively flat country characterized by gently sloping landscapes with some hills. Soils are generally poor, and prone to soil degradation. There are eight main soil groups across the country, but poorly evolved eroded soils and leached ferruginous soils occupy approximately two thirds of the surface. In general, these soils have a low nutrient content, particularly when it comes to phosphorus and nitrogen, and their depth is usually limited by a hardpan that in some cases emerges to surface. All soils suffer the effects of runoff and the consequent soil erosion (Roose, 1977). Wind erosion is most evident in the Sahelian zone, where the average annual rainfall is less or equal to 600 mm.

Based on variations in climate and vegetation, three agro-ecological zones are typified in Burkina Faso:

- **Sahelian zone:** located in the northern part of the country receives an average annual rainfall of 300–600 mm with the dry season extending from October to June. Bush and grasses dominate the landscape with few trees concentrating along seasonal rivers, as well as in humid depressions where rainfall is collected naturally. This zone permits a short crop-growing period of less than 100 days a year.
- **North Sudanese zone:** situated in the center of the country receives an average annual rainfall of 600–900 mm where the rainy season lasts from June to October. This zone is mainly characterized by a relatively dry savannah with mixed bushes and occasional trees.
- **South Sudanese zone:** located in the southern part of the country receives more

rainfall compared to the other zones, ranging between 900–1200 mm per annum. The rainy season continues for 6–7 months and the landscape is covered with dense and lush vegetation. This zone has a slightly longer crop-growing season of about 160 days per year where rain-fed agriculture is considered more favourable.

The country has several rivers but the Mouhoun and Comoé rivers are the only rivers that flow all-year round, while the others are seasonal rivers (AQUASTAT, 2015). Burkina Faso's renewable water resources are estimated to be 12.5 km^3 per year. Yet, only 6.5 percent of the total resources, which accounts to 818 million m^3 per year of the renewable water resources is utilized.

Agriculture Sector

Agriculture is a key contributor to Burkina Faso's economy, accounting for 30 percent of the Gross Domestic Product (GDP) in 2012 and engaging more than 90 percent of the working population (FAO, 2014a). Cereals and legumes are the main staple crops produced for consumption and sale in-country, whereas cotton is the main export crop (AQUASTAT, 2015). It is no surprise that agriculture is the principle source of revenue for the majority of the households (FAO/IWMI, 2010).

Agriculture is generally conducted at a small scale, with 95 percent of land holdings of 10 hectares or less and 73 percent at 5 hectares or less (FAO, 2014b). Cereal production (particularly millet and sorghum) constitutes the key agricultural component, providing 42 percent of household agricultural income (EBCVM, 2003 cited in FAO, 2008). The national government believes that improved AWM, including WH, is required for the sustainable development of agricultural production by small-scale farmers in Burkina Faso and to help ensure that crop yields cover the basic food needs of the population into the future.

Institutional Set-up

Inside the newly created *Ministère de l'Agriculture, des Ressources Hydrauliques, de l'Assainissement et de la Sécurité Alimentaire* (MARHASA), WH is managed through the General Directorate of Agricultural Management and Irrigation Development. The General Directorate was established with the goal to slowly shift to irrigated agriculture and securing the production of rain-fed agriculture. The management of degraded land (projected to be more than 1 Million hectares) and their rehabilitation is one of the chief objectives of the Directorate.

Within the General Directorate, the Directorate for Conservation of Soils (DCS) are directly responsible for WH at field level. The DCS is relatively new, and seeks to propel regional and national actions towards WH. Furthermore, it has begun to collaborate with several organizations to improve its internal capacities and stimulate cooperation. It has already established development and research partnerships with organizations such as "*Institut National de l'Environnement et des Recherches Agricoles"* (INERA), *"Institut International d'Ingénierie de l'Eau et de l'Environnement"* (2iE), and *"Deutsche Gesellschaft für Internationale Zusammenarbeit"* (GIZ).

One of the DCS's major activities is to implement more than 10 000 small WH ponds for small-scale irrigation (SSI) nationwide. The construction of WH ponds with storage capacities of 250–300 m^3 is planned to generate and improve food security and the production of cash crops. Ponds are designed to support staple crop production for four household members that use 0.25 hectares and where they can practice supplementary irrigation to overcome dry spells.

Capacity Building and Extension Services

Agricultural extension in Burkina Faso is currently provided by the MARHASA in collaboration with national and international NGOs, and public and private organizations. Other government ministries that are involved in extension services include the "Ministère de la Recherche Scientifique et de l'Innovation" (MRSI), the *"Ministère de l'Environnement et du Développement Durable",* and the *"Ministère des Resources Animals"*. In terms of research, INERA, 2iE, and the University of Ouagadougou are the main institutions to carry out research on AWM and WH.

As a result of structural adjustments programs, the network of extension agents has been strongly reduced in recent years and a single extension agent has to cover a whole department on his/her own. Furthermore, extension agents also generally have insufficient technical knowledge and change positions rapidly. Nonetheless, there is an increasing number of experienced agricultural organizations that are capable to provide technical advice on topics traditionally covered by the agricultural extension service.

Potential and Needs for Water Harvesting

Investments in water harvesting techniques are highly important in Burkina Faso. While some WH techniques have been used for many generations such as the "zaï" pits that originated from local practice, other techniques have been introduced through various development projects implemented in the country since the 1960s, such as WH ponds and the "Vallerani" System – "Delfino". The use of WH techniques is particularly high in the Central Plateau region, where techniques have been adopted by farmers in collaboration with state departments to fight against environmental degradation and cope with the impacts of climate variability on agriculture and the environment.

Due to the high variability of rainfall in space, time, and volume, a wide range of WH techniques exist in the country. These include: techniques to control runoff and sedimentation by increasing infiltration ("zai", half-moons, earth bunds, stone bunds and stone lines, grass strips, etc.); techniques that improve soil structure, water infiltration, water-soil-plant relations and mineralisation processes by stimulating biological activity in the soil (zai, mulching, composting, etc.); and techniques that provide the opportunity for supplementary irrigation by storing water in surface reservoirs (boulis etc.).

Soil moisture storage techniques in Burkina Faso are proven technologies, which are well accepted, by technicians and farmers alike. This achievement can be strengthened by recognizing local success stories and by fostering grassroots knowledge transfer such as farmer field schools (FFS), farmer's innovations and farmer-to –farmer approaches. In many cases, farmers are familiar with the techniques, but the costs of inputs (e.g. stones for stone lines) and design faults can pose barriers to implementation. The lack of biomass and organic fertilizers is also a recurrent challenge, as it prevents improved soil moisture retention and therefore higher crop productivity. As such, soil organic matter and soil fertility management need to be integrated with WH techniques to ensure best performance.

In general, there is growing consideration of rain-fed agriculture and the management of rainwater at both government and local level, but there is still a lack of coordination of different efforts and adaptation of techniques to local contexts. In terms of training of implementers, WH is covered in existing curricula to different extents, however, there are opportunities to strengthen educational and research programs. Due to the simplicity of most WH techniques, it is essential to focus capacity building on practical training.

Morocco

Climate and Physical Landscape

Morocco is an arid to semi-arid country with two main seasons; a cold and humid winter followed by a warm, dry summer. The climate is characterized by irregular and uncertain rainfall, frequent seasonal and pluri-annual dry spells, as well as damaging floods. The annual average rainfall is 346 mm, which mostly occurs between autumn and spring. However, this average value conceals a dramatic geographic difference: the Northwest receives on average 700 mm per year, thus making rain-fed farming possible; the Southeast receives only 25 mm per year, making irrigation essential for agricultural production (AQUASTAT, 2015).

Morocco is a country with a variety of landscapes from the rich coastal plains, the northern coast and interior dominated by mountains, large plateaus, and valleys (AQUASTAT, 2015). Soil erosion and land degradation are problematic and affect 50 percent of the upper catchment areas of dams (20 million hectares). The main driving factors are the presence of steep and unstable slopes, poor and sparse vegetation, uncertain rainfall patterns and frequent dry spells. Anthropogenic factors such as overgrazing and increasing pressure on cultivated land, deforestation, and inadequate agronomic practices also contribute to an increase in soil erosion and land degradation. In the Atlantic zone, soils are generally more stable and fertile than in the rest of the country, and destructive runoff is absent due to the gentle slopes

Based on climate and physical landscape, Morocco may be subdivided into six AEZ based on temperature, rainfall, and topography:

- **Desert** (rainfall < 100 mm): Sahara and Pre-Sahara, Eastern Anti-Atlas, Southern slope of High-Atlas
- **Atlantic and Eastern arid steppe** (rainfall 100-300 mm)
- **Arid mountains** (rainfall 100-300 mm): Southern and Eastern High-Atlas, Western Anti-Atlas
- **Atlantic and Mediterranean plains and plateaus** (rainfall 300-600 mm)
- **Semi-arid mountains** (rainfall 300-600 mm): Central and Western High-Atlas, Pre-Rif and Eastern Rif
- **Humid and sub-humid mountains** (rainfall > 600 mm): Pre-Rif and Western Rif, Middle Atlas

Agriculture Sector

Agriculture contributes a large share to Morocco's GDP, ranging from 15 to 20 percent depending on the season. It is the first provider of employment, employing 38 percent of the population at the national level and 75 percent in rural areas (Balaghi, 2014). Many traditional and smallholder farmers depend on rain-fed agricultural production, which is an important source of livelihood. To date, only 16 percent of the cultivated land is under irrigation (Balaghi, 2014) while the remaining cultivated land is rain-fed. In rain-fed areas, irregular rainfall and frequent dry spells count as main factors for low agricultural productivity.

Most of the country cannot grow crops and improve production levels without the application of irrigation. Rising water demands due to population increase and economic growth, alongside decreasing storage capacity caused by siltation of dams and increasing uncertainty of rainfall patterns, have made water scarcity more acute. This creates a challenge for agriculture and local human development, particularly in marginal areas that lack adequate access to irrigation.

Institutional Set-up

Since Morocco's independence, the government has channelled a lot of investments in the irrigation sector, in large, medium, small scale irrigation systems, making it a leading sector to improve agricultural and economic development (Doukkali, 2005). This is in line with achieving the "million hectare" policy, with over 1.5 million irrigated hectares (Hammani, 2014). In the past few decades, Morocco has renewed its focus on indigenous sustainable land management and WH by adopting an integrated approach to water resources development and management. The reason behind this shift lies upon several factors such as, soil erosion and land degradation coupled with physical limits for freshwater expansion via large-scale water development schemes, water scarcity, siltation of dams, as well as increased awareness about the potential of increasing rain-fed agriculture.

The main governmental actors financing and implementing WH in Morocco are the *"Ministère de l'Agriculture et de la Peche Maritime"* (MAPM) and particularly the *"Direction de l'Irrigation et de l'Amenagement de l'Espace Agricole"* (DIAEA). Within its policy and planning approach, the Plan Maroc Vert (2008-2020), the Ministry has vigorously encouraged the application of SLM, especially for small-scale farming in arid and semi-arid areas. The objectives of this work are four-fold:

- Improving water availability to increase biomass production in rain-fed areas;
- Reducing water scarcity for livestock;
- Combat desertification through the introduction of tree and shrub plantations; and
- Improving rural livelihoods by introducing adapted cropping systems.

Besides MAPM, the *Ministère déléguée chargée de l'Eau* (MDCE), the *Haut Commissariat aux Eaux et Forts et à la Lutte Contre la Désertification* (HCEFLCD), INRA, ENAM, IAV, the *Office National du Conseil Agricole* (ONCA), and International development organizations have an important role in promoting water harvesting uptake in Morocco.

Capacity Building and Extension Services

The agricultural extension system in Morocco is a multi-layered structure that has a presence in the national, regional, provincial, and local settings (MAPM, 2011). Aside from the government, there are also independent extension initiatives supported by NGOs, which work on projects developed by private companies engaged in agriculture or initiated by international organizations (MAPM, 2011; Al Balghiti and Mouaaid, 2010). There is also a wide variety of agricultural research institutes such as, ENAM, INRA and IAV that undertake relevant research and train future agricultural engineers.

There are several challenges that hinder the effectiveness and continuation of agricultural extension services. In Morocco, the main challenges regarding the extension service are insufficient resources in terms of knowledge and funding to provide the variety or services needed (marketing, economics, natural resources management and project management). As a result, extension services are mainly limited to irrigated areas, whereas agricultural extension agents are limited in the peripheral, rain-fed areas. To combat these problems the ONCA is attempting to restructure and strengthen local extension centres and regional chambers of agriculture (MAPM 2011; Al Balghiti and Mouaaid, 2010).

Potential and Needs for Water Harvesting

Morocco has a long tradition in WH and SLM. Local communities have developed and adapted their farming strategies and skills to the changing climatic conditions by integrating a wide range of diverse physical structures in their landscapes. Many traditional WH techniques, however, have fallen into disrepair due to the degradation of land and water resources and agrarian and socio-economic drivers like, out-migration, intensification and modernization of agriculture. As a result, serious gully erosion and landslides have occurred.

Over the past decades, much attention was paid to large-scale infrastructure, however, this has shifted to decentralized, small-medium scale, and locally adaptable and manageable techniques, including WH. WH in Morocco is embedded in a strategy that combines erosion control, soil moisture enhancement, water storage in reservoirs, and drainage of surplus water combined with biological measures, such as agroforestry, cover crops and reforestation. However, the suitability and adoption of the various WH techniques varies greatly between different regions and communities. Past projects have failed partly because of poor attention to endogenous knowledge and techniques that have been developed in synergy with climate, relief, water resources, local habits, local production systems and social organization (Roose *et al*., 2010).

Future interventions require deeper understanding of the local socio-economic and agrarian context, as well as of the regional diversity of existing WH and SLM practices. This will allow for the identification of a series of improved WH techniques that are well adapted to local agro-ecological and socio-economic conditions. Discussions are also needed between research institutes and ministry departments on how to improve the link between WH, SLM and groundwater recharge via small-scale, cost-effective structures and agronomic measures. Groundwater recharge is still limited in Morocco, regardless of the great potential (particularly in areas where groundwater experiences saline intrusion). At local level, the application of pilots and demonstration plots where farmers can observe and experience the actual benefits of techniques will also be needed to stimulate interest and acceptance of the techniques.

Water harvesting: Effects and upscaling

Photo© M. Gurtner, GIZ

The importance of micro-climates in crop productivity

Micro-climates refer to distinctive localized zones, such as a field or small watershed, where the climate differs from the climate around it (the macro-climate). Micro-climates are defined by a multitude of elements such as, wind direction, air temperature and humidity, soil temperature and moisture, which are influenced by day and night, as well as by seasonal variations. They are landscape-specific and influenced by vegetation, topography, land use, soil characteristics, hydrological regimes and water management (van Steenbergen and Mehari Haile, 2015).

Micro climates determine important processes that influence agricultural production, such as evaporation, transpiration, soil moisture retention, temperature, the dynamism of soil nutrients and the manifestation of diseases and pests. As a result of their influence on these processes, micro-climates hold great potential to augment the capacity of the ecosystem to sustain agricultural production and provide a buffer against climate change. Nevertheless, their management is often ignored and not well understood.

Influencing micro-climates through water harvesting

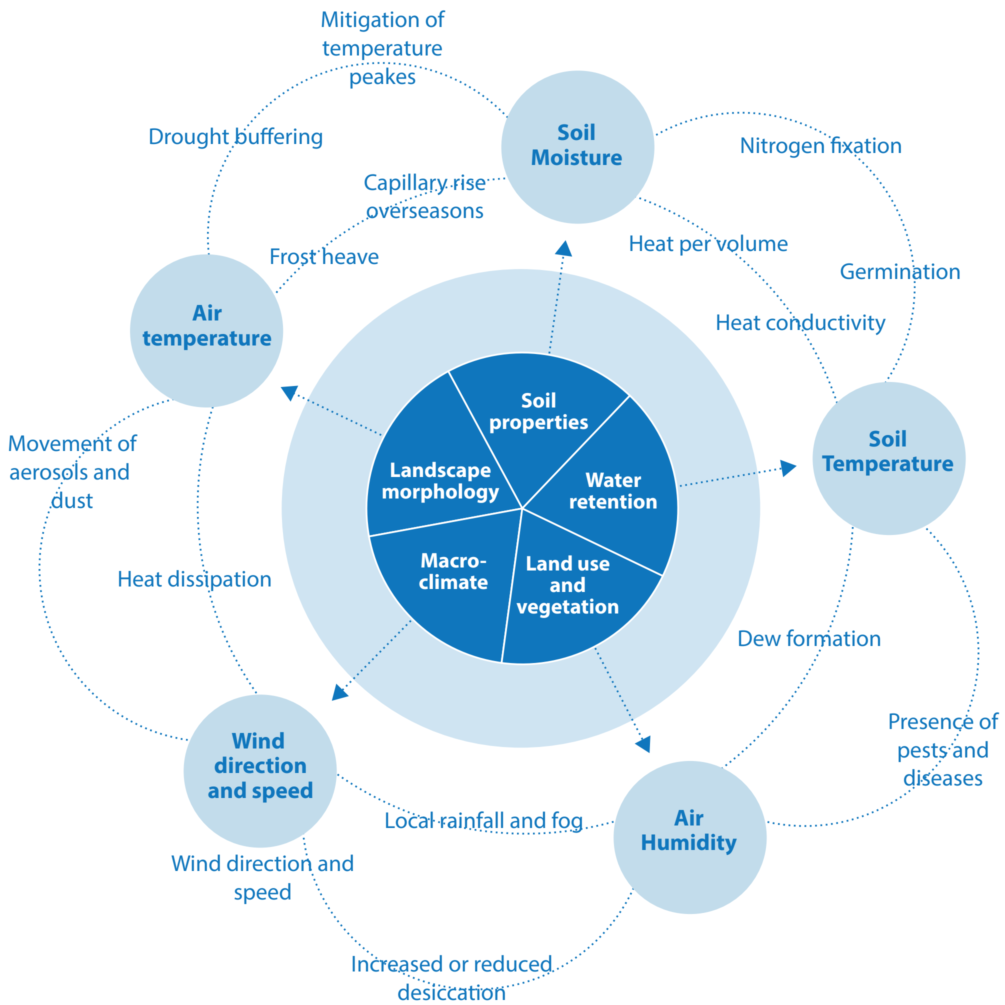
Soil and water are key and intertwined elements in micro-climates, and WH can have a direct influence on both, as shown in Figure 1. The primary influence of most WH techniques is to increase levels of water retention and hence soil moisture at a landscape level. As more moisture is available in a landscape, temperature peaks and lows begin to even out – both in the air and the soil at various depths. Improved soil moisture also enhance the ability of soil bacteria to stimulate nitrogen fixation, which augments the overall fertility of the landscape. WH can also help to control water runoff and avoid excessive soil erosion, ensuring that nutrient rich sediments are not flushed out from the farming system.

Enhancing WH capacity for agriculture, therefore, requires the ability to select feasible, suited and well-performing WH techniques for different areas that enhance these processes and have a positive impact on the micro-climate.

Knowing which WH techniques to promote where

Enhancing WH capacity for agriculture requires planning and management of landscapes to meet multiple objectives and stakeholder needs, including agricultural production, livelihood improvement and ecosystem conservation. It is thus critical to know what to do where, how to manage water buffering processes/techniques, how water flows, where it infiltrates, where it can be stored and retained, which type of land cover and land management enhance these processes, and how the micro-climate is affected (Knoop *et al.*, 2012). Landscape transformation depends much on the potential recharge capacity and water storage.

Figure 1: Infographic on the effect of WH techniques on micro-climate



(Source: MetaMeta, 2015)

It is important to consider that there are no blueprints for implementing WH at scale, it requires local planning, local innovation and local leadership. Box 1 describes the most important principles of successful water harvesting that need to be acknowledged. In line with these principles, the purpose of this assessment is to reassess WH techniques that have already been implemented in the three studied countries and observe how they are affecting the areas in which they are used. This will enable the identification of the top performing techniques to be further tested, which will in turn provide an indication of changes that need to be made to improve their influence and enable more effective upscaling.

BOX 1: 8 principles of successful water harvesting

1) Start with a long, careful and thoughtful observation of the landscape.
   - Where is the water flowing and how?
   - What is working and not?
   - Then built on what works

2) Begin at the top of the catchment/watershed and work downwards.
   - Water moves downhill.
   - Collect water at the top for direct infiltration.
   - Begin at the top where the volume and velocity of water is not greatest, making it easier to manage.

3) Begin simple and small.
   - Work on human scale to make operation and maintenance manageable.
   - Many small strategies are more efficient compared to larger ones, especially when trying to improve infiltration in the soil.

4) Spread and infiltrate the flow of water.
   - Encourage water retention and storage to improve infiltration into the soil by slowing down the force of water and spreading it.

5) Constantly plan an overflow route so that it is possible to manage the overflow as a resource.
   - An overflow route is necessary, especially during extremely heavy rains and where conceivable to apply the overflow as a resource.

6) Establish a living sponge.
   - Increase flora and fauna to create a living sponge so that harvested water is applied to grow more resources, whilst the soil manages to infiltrate and retain water continuously for improvement.

7) Do not perform piecemeal interventions, the more the better.
   - Mix different techniques and functions to maximize benefits.

8) Constantly reassess the implemented systems: "feedback loop."
   - Observe how the implemented techniques influence the area – starting again with the first principle.
   - Adjust to unexpected developments by applying the above principles.

Source: Lancaster, 2008

Methodology: Multi-Criteria Analysis (MCA)

Photo: ©FAO/Giulio Napolitano

MCA methodology

There are several methods for multi-criteria analysis (MCA). For this purpose, the MULTIPOL method was chosen for its flexibility and its ability to integrate uncertainties and conflicting judgements. MULTIPOL consists of the evaluation of specific actions (WH techniques in this case) through a weighted average. The method involves all steps of a typical MCA, as outlined below.

The analysis was based first on a comprehensive review of available literature and second on interviews with national experts from technical ministerial departments, agricultural research institutes, and NGOs working on water harvesting. Hence, the final selection of criteria and indicators occurred with the direct participation of stakeholders. Preliminary results were validated during final workshops with various institutional stakeholders and amendments and observations were integrated in the final results.

BOX 2: Understanding Criteria and Indicators

Criterion: is a standard or principle by which a thing/item/mechanism is judged.

Indicator: can be any variable or component of a project, scheme, and structure or management systems used to deduce the condition of a specific criterion. Indicators need to transfer or transmit a single important message or information that embodies one or more data elements with specific formed links.

Source: Mendoza *et al*. 1999

The MULTIPOL method used in this assessment consisted of several steps:

1. **Selection of WH techniques to evaluate with the MCA**

The MCA focused on those WH techniques that are already known and implemented in the three countries and for which there is existing data on their performance.

2. **Definition of evaluation criteria**

Evaluation criteria were pre-selected and weighted on the basis of the level of importance in determining the suitability of WH techniques according to literature review and stakeholder consultation. The four criteria and their associated weights are presented in Table 1. Greater weight is given to the agricultural productivity in the calculation of the overall performance of each technique.

Table 1: The criteria used to evaluate WH techniques in the MCA and their associated weights

Criteria	Weighting
Geographical suitability	10
Technical and environmental suitability	30
Socio-economic suitability	20
Agricultural productivity and profitability impact	40

3. Selection of evaluation indicators and sub-indicators for each criterion

In order to assess the degree to which the WH techniques satisfied the criteria, a range of indicators were selected. All indicators had the same weight in the contribution they provided to their relevant criterion. The final list of indicators, as shown in Table 2, were the product of literature review and stakeholder interviews.

Table 2: Criteria and associated indicators used in the MCA

Criteria		Indicators	Description
A. Geographical suitability	1	Agro-ecological zones	WH techniques potentially applicable in a wider variety of AEZ within a given country received a higher score.
B. Technical and environmental suitability	1	Storage type	A measure of the potential of each WH technique to increase the water buffer at landscape scale, i.e. its contribution to the hydrological cycle.
	2	Storage capacity	A measure of the volume of water that can be stored by a specific WH technique. This indicator applies only to water storage in open or closed reservoirs.
	3	Soil quality	A measure of the positive impacts of each technique on soil properties (physical, chemical, biological) and against soil erosion.
C. Socio-economic suitability	1	Multiple uses of water	A measures of the use of water stored by a certain WH technique. Techniques that contribute to more uses received a higher score.
	2	Costs	Consider investment, operation and maintenance costs (often expressed in labour requirements) for each technique and attaches a lower value to those techniques having higher costs.
	3	Management and maintenance capacity	Provide information on the availability of local expertise and capacity to maintain and manage the techniques.
	4	Gender	A qualitative assessment of the implications of the different techniques for both men and women. For instance, techniques that increase workload of women or favour men more than women score lower.

D. Agricultural productivity and profitability impact	1	Productivity	A measure of the quantitative increase in crop yields compared to control (same crop without the adoption of the WH technique).
	2	Diversification	A measure of the extent to which agricultural production can be diversified (also introducing higher value crops) thanks to the adoption of the technique.
	3	Profitability	Inform on the relation between revenue obtained or anticipated by the farmer (long-term) and the resources deployed to obtain the revenue (cost-benefit).

4. Evaluation

A total of 42 implemented and best practice WH techniques across the three countries were selected for evaluation (11 surface water, 6 groundwater and 25 soil moisture techniques). Table 3 summarizes the implemented techniques examined per country.

For each WH technique, every indicator was assigned a score based on available quantitative and qualitative data collected from documents and stakeholder consultation. The score given was determined by the level of satisfaction the WH technique provided within each indicators. A score of between 0 and 5 was assigned to each indicator, where 0 represented unsatisfactory and 5 represented fully satisfied. The final scores assigned to the criteria for each technique represent the mean of scores given for each of the indicators within that criterion.

5. Integration of scores

For each technique, the weighted average of the different scores obtained for each criterion was calculated, as well as the standard deviation. Risks related to uncertainties or conflicting judgements were internalized by considering average scores for the different criteria together with the standard deviation of the component scores. This way, it was possible to test the robustness of results for each assessed WH technique: a technique scoring high but showing high standard deviation was considered risky.

6. Ranking of WH technologies

This final step involved the ranking of the evaluated WH techniques based on the final score.

Limits of the evaluation

The main limitation of this assessment was the unequal amount of data available for the different WH techniques evaluated. Whereas much information was available for some water harvesting techniques, such as valley tanks and valley dams, it proved more difficult to evaluate, for instance, the impact on productivity and profitability of tube recharge, rock catchments and stone bunds.

Table 3: Overview of techniques examined across the three countries in this assessment

WH technique	U	B	M
WH from Roads	o	o	o
Small WH Ponds	o	o	
WH from Rock Outcrops	o		
Permeable Rock Dams	o		
Rooftop WH	o		
Valley Dams	o		
Valley Tanks	o		
Covered cisterns/ Matfias			o
Hill lake			o
WH ponds (farm, iferd)			o
Les Mares surcreusées/ Boulis		o	
Gully Plugging	o		
Subsurface Dams	o	o	
Tube Recharge	o	o	
Sand Dams	o	o	
Percolation ponds & contour trenches		o	
Khettar			o
Contour Bunds	o		
Demi lunes	o	o	
Grass Strips	o	o	
Improved Trash-lines	o		

WH technique	U	B	M
Mulching	o	o	
Terraces	o		o
Trapezoidal bunds	o		
WH for Banana Plantations	o		
Stone bunds	o		
Spate irrigation	o		
Fanya juu,/ Fanya chini	o		
Agricultural benches		o	
Digues filtrantes (Filtering dikes)		o	
Fumier and Compost		o	
Vallerani system (delfino)		o	
Zaï pits		o	
Tied ridges		o	
Agroforestry		o	
Water spreading weirs		o	
Check dams			o
Conservation agriculture			o
Jessours			o
Micro-basins			o
R'Foussi			o
Water and sediment control basin			o

Surface water Groundwater Soil moisture

Photo: ©FAO/Tamiru Legesse

Results of the Multi-Criteria Analysis

Uganda

The MCA for Uganda evaluated the 21 most common and effective WH techniques in the country, as outlined in Table 3. Performance of the techniques was found to range from 31 percent to 78 percent, with all but three WH techniques above 50 percent and eight scoring above 70 percent. The standard deviation of criteria scores varied greatly between techniques. The top five performing WH techniques (WH from roads, small WH ponds, valley tanks, contour bunds and WH for banana plantations) and their associated scores are shown in Table 4.

Table 4: MCA results for top five performing WH techniques in Uganda

WH technique	Criteria				Weighted performance score
	A	B	C	D	
WH from roads	4.50	3.22	3.85	3.33	78%
Small WH ponds	4.50	2.78	3.40	3.67	75%
Valley tanks	3.00	3.22	3.35	3.67	75%
Contour Bunds	3.50	3.50	2.85	3.67	74%
WH for banana plantations	3.50	2.50	3.20	4.00	73%

Storage/diversion measures such as small WH ponds, valley tanks and WH from roads emerged as the strongest technologies in the MCA, scoring consistently high across all four criteria. These measures have great scope in providing supplementary water for agricultural production in Uganda during the dry season, as well as during the common dry spells in the wet season. Nevertheless, in accordance with the 3R approach outlined previously, it is advised to combine these storage/diversion techniques in a system together with techniques that favour soil moisture retention, soil fertility and plant health. Consequently, measures such as contour bunds and WH for banana plantations, which also performed well in the MCA, can enrich the farming system and help to increase rain-fed production. The use of mulching, which was eighth highest scoring in the MCA, as part of a landscape wide WH system would also be beneficial and enable further increase in soil moisture storage.

A description of each technology and explanation of their allocated scores is provided in the following pages.

Water Harvesting from Roads

During heavy rains the second nature of many roads becomes apparent: they intercept surface runoff and generate streams on their relatively compact surfaces. The location of the road in relation to contour lines, the height of the embankment, the longitudinal and lateral slope of the road, the surface material and the under drainage are all important factors in determining how much runoff is generated from a road and hence how water can be retained (van Steenbergen and Tuinhof, 2010). Rainwater can be harvested from the road surface (depending on the type e.g. tarmac, gravel, etc.), whereby the road drainage can be used to convey the water for storage or recharge (see Figure 2).

Figure 2: Example of an embankment pond fed by a road culvert

(Source: F. Sambalino, MetaMeta, 2015)

Geographical suitability: The technique is very suitable for arid and semi-arid areas where water productivity should be maximized, but also for other areas if combined with reservoirs (to store water for small-scale irrigation) or if the water is infiltrated into the ground to improve soil moisture and replenish ground water. The numerous opportunities in terms of roads spread across the country make water harvesting from roads attractive in all AEZs.

Technical & Environmental factors: Water from roads can either be used to improve soil moisture, or stored in reservoirs and used for various purposes. When water from roads is stored in the permeable reservoirs it can slowly infiltrate into deeper layers of soil, therefore replenishing (shallow) ground water aquifers. Because of the large volumes of water that can be potentially collected per kilometer of road, there is a high chance to harvest and store that water in a reservoir. Road water harvesting also helps in decreasing soil erosion that commonly occurs along drains and below road culverts

Socio-Economic factors: Road runoff can be successfully spread directly over farmland, thus increasing the amount of water available for crop production. WH from roads is adaptable and can be used in combination with other techniques that match the capacities of farmers. If the water from roads is stored in reservoirs, it can also be used for (small scale) irrigation, watering animals, and for domestic purposes, provided it is adequately treated.

Productivity and profitability: Water harvesting from roads can significantly improve agricultural productivity of the land, the level of influence depends on whether water harvested is used directly or stored. Where water is harvested and used directly to support runoff farming, it improves crop productivity and profitability by increasing soil water availability over time. If water channelled from roads is stored in reservoirs or basins, it can be successfully used for supplementary irrigation, thus increasing productivity and lowering crop risks related to dry spells; this also gives an advantage to farmers in the form of higher prices in times of drought.

Small Water Harvesting Ponds

Water harvesting ponds can be designed in various shapes, materials and dimensions such as, circular, square and rectangular ponds (Knoop *et al*., 2012). Water is collected in the pond by channelling water from surrounding fields, ephemeral streams, paved surfaces (paths, roads), channels (cut-off drains) or naturally sloping surfaces, as shown in Figure 3. They are usually constructed near homesteads for easy access. Soils with a high content of clay are preferable for constructing small water harvesting ponds as they have low permeability. Alternatively, the bottom of the pond can be reinforced with cement mortar and wire mesh, paved with rocks, puddled with clay or plastic sheets where needed (Desta *et al.,* 2005).

Figure 3: Runoff flowing into a small water harvesting pond

(Source: Government of Ethiopia, 2015)

Geographical suitability: Water harvesting ponds have great adaptability in their geographical application. Their shape, positioning, impermeable lining and source of water can all be adapted to match the local conditions and needs. Due to this characteristic small water harvesting ponds can be applied successfully in all AEZs.

Technical & Environmental factors: If the pond is not lined then the water can seep into the soil where it replenishes (shallow) ground water and, to a limited extent, the soil water moisture in the immediate surroundings. Impact on soil quality and erosion is limited to the control of runoff and thus to buffer the effect of high intensity downpours in downstream areas.

Socio-Economic factors: The water stored in ponds can be used for irrigation, watering animals, domestic purposes (if treated). Ponds have been used in Uganda already and therefore there is considerable knowledge regarding their implementation and maintenance. Water from the ponds can be used to irrigate high value crops like vegetables during the dry season, either for home consumption or sale. This can increase a household's food security and income, uplifting household welfare.

Productivity and profitability: When used for small irrigation, WH ponds can increase household income and crop productivity, as well as helping to diversify crop production. Vegetables are commonly grown in small scale irrigation schemes linked to the ponds.

Valley Tanks

Valley tanks are open surface water reservoirs with a volume that ranges between 10 000 and 25 000 m^3 and are generally constructed to reduce water deficiencies experienced by pastoral communities in areas such as Karamoja region in north-eastern Uganda and the cattle corridor (see Figure 4). Valley tanks are commonly found on gently sloping valleys because these areas can generate sufficient runoff water that can be channelled and collected in the dugout reservoirs.

Geographical suitability: Valley tanks are constructed in districts where rainfall is between 250–750 mm per annum. Valley tanks have high adoption rates in pastoral areas of the cattle corridor, which are located in the pastoral semi-arid AEZ, Northern and Eastern short grassland AEZ, and to some extent in the Southern and Western tall grassland AEZ. These tanks are particularly suitable in stable catchments where water drains through a gently undulating landscape. In order to minimize seepage losses, the tanks must be placed in deep impermeable soils, with a high percentage of clay content. To decrease the amount of excavation work, valley tanks are better implemented in pre-existing depressions.

Technical & Environmental factors: Valley tanks are reservoirs with medium storage capacity. Depending on the soil and aquifer characteristics they may have a strong influence on the recharge of groundwater, which can in turn stimulate the use of shallow groundwater. Soil moisture content is also likely to increase in the immediate surrounding of the tank. The impact on soil erosion and soil fertility is limited and in fact, when soil erosion occurs in the valley tank catchment it can severely hinder storage capacity and water quality of the structure.

Figure 4: Excavated valley tank

(Source: J. Kisekka, 2015)

Socio-Economic factors: Valley tanks are mostly used to water livestock in pastoral areas, but use can be easily extended to support small scale irrigation and domestic use with appropriate water treatment. The ecosystem benefits from tanks that act as flood peak regulators, provide water for wildlife and vegetation and stimulate groundwater recharge. However, valley tanks are relatively high cost and need complex management in place in order to assure that silt is removed seasonally and water abstraction structures are properly maintained. Labour is not generally a constraint to the adoption of the structures, which are commonly constructed with heavy machinery funded by the government or NGOs. Valley tanks may have a positive impact on women's lives by providing a water source and decreasing the amount of time spent looking for water.

Productivity and profitability: Where used for livestock related activities, valley tanks increase the health, weight and thus profitability of livestock production. When coupled with small scale irrigation, valley tanks also increase the productivity of crop production through supplementary irrigation. The newly available source of water also allows farmers to move into the production of cash crops, such as vegetables, which are not possible in a rain-fed regime.

Contour Bunds

Contour bunds are small structures that control erosion, improve infiltration and improve crop yields (Knoop *et al*., 2012). The bunds are usually built on hillsides along contours (see figure 5). Contour bunds reduce the speed of run-off, which allows the water to infiltrate, thus improving the soil moisture. Contour bunds come in various designs: stone bunds, soil bunds, tied ridges and stone face bunds.

Figure 5: Soil bund in red sorghum field

(Source: MetaMeta, 2014)

Geographical suitability: Because of the high runoff velocities and therefore increased probability of soil erosion in areas with steep slopes, contour bunds are suitable for use in both the high altitude AEZ and southern and western tall grassland AEZ. However, bunds can also be applied on low slopes, such as in the pastoral arid to semi-arid AEZ and in northern and eastern short grassland AEZ, although provision must be made to avoid livestock damaging the structures. Contour bunds are usually implemented on slopes below 15 percent and above 3 percent, preferably on well-drained soils.

Technical & Environmental factors: By intercepting and holding runoff the bund increases water infiltration in the soil, improving soil moisture and, to a limited extent, replenishing shallow ground water. Soil bunds are very effective in diminishing erosion in the farm and in trapping suspended sediments. The fertile sediments accumulate behind the bund, which after some seasons creates a highly fertile bench.

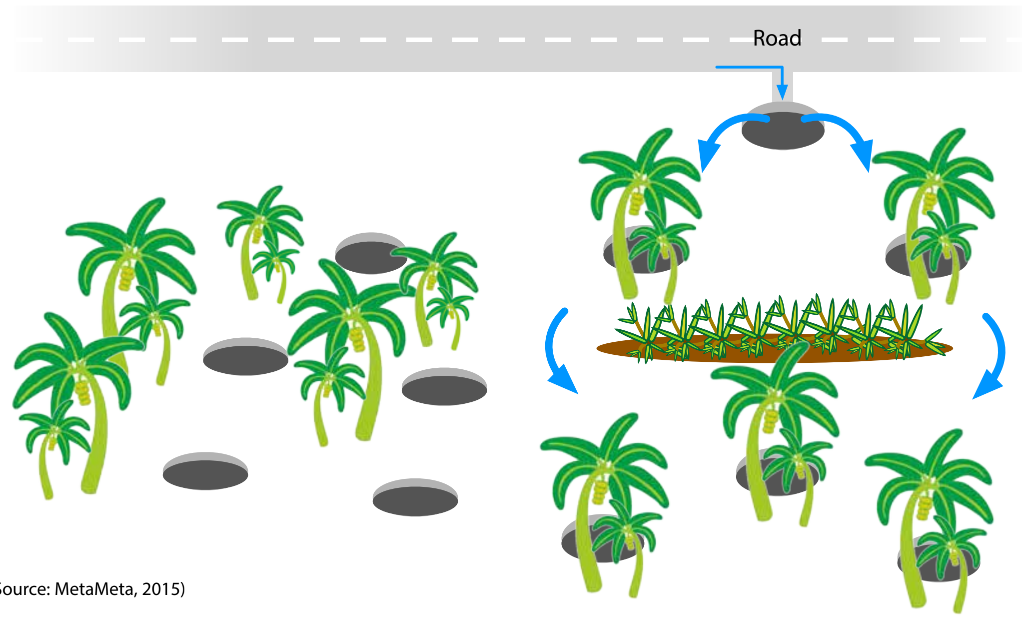
Socio-Economic factors: Contour bunds are valued for their importance in trapping water in the soil profile, which increases levels of rain-fed production. Furthermore, contour bunds are very valuable for catchment restoration activities, for which they provide considerable environmental services by reducing the risk of soil erosion and increased water infiltration. Farmers have the capacity to manage and maintain contour bunds themselves, but would benefit from training to improve their skills. Constructing and maintaining contour bunds is labour intensive, and because women constitute the biggest labour in agriculture, this technology is likely to substantially increase the workload of women.

Productivity and profitability: The augmented soil moisture content and accumulated sediments immediately above the soil bunds lead to higher production in comparison to non-bunded fields. Bunds are commonly strengthened with edible grasses or bushes, such as pigeon pea, which provide a way to diversify farm production.

Water Harvesting for Banana Plantations

Water harvesting for banana plantations is an in-situ WH technique, which was implemented through the Farmers Field Schools (FFS) approach in the Mabarara District to improve soil moisture retention and soil fertility. Two types of techniques are used: (1) a simple banana planting pit; and (2) road water harvesting banana plantation pits (see Figure 6).

Figure 6: Banana planting pits



(Source: MetaMeta, 2015)

Geographical suitability: Can be potentially applied in all banana growing counties of Uganda where a source of steady runoff water is available. Road water harvesting is commonly used for this purpose, whereby water is channelled from the road, stored and transferred to the planting pits.

Technical & Environmental factors: Through the implementation of interconnected soaking pits, this technology considerably increases the amount of water available to banana plants. The soil profile surrounding the soaking pits is kept moist for a prolonged amount of time. The soaking pits, when applied at high density, also have an impact on the recharge of shallow aquifers. Furthermore, the pits also have an important role in improving soil fertility. Organic material is commonly added to each pit, thus increasing its water retention capability, but also providing a source of nutrients to nearby plants.

Socio-Economic factors: WH for banana plantations is a form of WH solely being used for agricultural production. It has a positive impact on the environment due to its capacity to decrease runoff erosion and increasing infiltration of water. It is a very economical form of water harvesting that can be easily replicated by farmers without external inputs. The labour requirement can be high during establishment, but its implementation can be conducted gradually over the period of several years. The maintenance labour requirements are minimal.

Productivity and profitability: Banana plantation productivity greatly benefits from the additional water and nutrients provided by the soaking pits (up to 300 percent yield increase). Some farmers plant beans, cabbages and other high value vegetable crops on the side of the pit thus diversifying their production and increasing the profitability of farming activities.

Burkina Faso

The MCA for Burkina Faso evaluated the 17 most common and effective WH techniques in the country, as outlined in Table 3. All but one of the WH techniques scored above 70 percent for overall performance, with half scoring above 85 percent. The standard deviation of criteria scores varied greatly between techniques. The top five performing WH techniques were manure and compost, grass strips, mulching, road water harvesting and demi lunes; their associated scores are shown in Table 5.

Table 5: MCA results for top five performing WH techniques in Burkina Faso

WH technique	Criteria				Weighted performance score
	A	B	C	D	
Manure and compost	4.88	3.67	4.05	4.67	93%
Grass strips	4.13	4.17	4.45	4.00	92%
Mulching	4.25	3.17	4.45	4.00	86%
WH from roads	4.63	4.11	3.20	4.00	85%
Half-moons	3.25	4.00	3.50	4.00	84%

In Burkina Faso, agronomic measures (composting, grass stripping and mulching) were found to be the top performing techniques as they accommodate the needs, scale, and capacities of smallholder farmers. The positive impact of these techniques on water harvesting results from their regenerative action on soils in terms of build-up of soil organic matter and other beneficial materials, improved soil structure, infiltration and water retention. In very dry areas of Burkina Faso, however, competition for scarce biomass between different uses (livestock, energy, and construction) can be a limiting factor to the implementation of composting, grass striping and mulching. Moreover, farmers would be more encouraged to allocate part of their land to grass strips if these were grown with (permanent) fodder crops that can be used as animal feed, in addition to their role in erosion control and improving runoff infiltration.

In line with the 3R approach, use of composting, grass striping and mulching (which focus on increasing soil moisture retention, soil fertility and plant health) should be combined with other larger-scale water diversion and storage techniques. A possible configuration that might be appropriate for further testing and upscaling in Burkina Faso includes channelling of water from roads, natural drains or other impervious areas into a system of micro-basins, such as demi lunes. Together with the application of high quality compost to the associated agro-forestry or cropping systems, this combination of WH techniques would increase infiltration and soil water retention, enhance soil microbiology and improve nutrient availability for plant growth.

A brief description of each technology and explanation of their MCA scores is provided in the following pages.

Manure and Compost

Organic matter is an important element of healthy soil ecology, it stabilizes soil temperature, favours the activity of micro-organisms, and is a source of nutrients that are gradually released into the soil in a form that is available for plant absorption. Furthermore, soils that are rich in organic matter have better porosity and structure, which leads to better water retention capacity. According to Desta *et al*., (2005), organic matter in the form of compost and/or manure from the farmyard and mixed in the soil can absorb and hold water by 4–7 times its own mass. Four main methods that incorporate and/or produce high quality organic matter used in Burkina Faso are: Le Tampoure', Fosse Fumiere, Aerobic composting process, Le Parc d'Hivernage.

Figure 7: Farmers working on aerobic composting process

(Source: L. Bunclark, 2013)

Geographical suitability: The use of manure and compost is suited to well-drained soils (silty, gravelly or sandy). The choice over the inputs to use to produce compost and manure are dictated by the proximity of the production area to houses, availability of organic waste, biomass (dry/wet), availability of livestock dung, and proximity to fields of application. The collection of animal dung for application in the field is conducted across Burkina Faso. Manure is collected to fertilize farmland destined for the production of food, market crops, and agroforestry. Manure and compost application suits all soil types (CILSS, 2012).

Technical & Environmental factors: The application of manure increases soil organic matter content, improves soil structure and porosity, and increases water holding capacity. The increase in organic matter also improves soil infiltration capacity, which may contribute to the recharge of shallow groundwater. If properly prepared (see Figure 7) and applied in right quantities, animal manure (camel, horse or donkey, cattle, poultry) can substantially improve soil quality and fertility. An increase in soil organic matter in turn make soil less susceptible to erosion from both wind and water.

Socio-Economic factors: Labour required for the preparation of manure heaps (e.g. the excavation of manure pits and the whole maturation process) increases total costs of this practice. The technique is quite simple and can be well managed by individual farmers. The impact of this technology on women, however, may be high considering the time and work that the production of compost requires.

Productivity and profitability: The application of 5 or 10 t/ha of compost can lead to yield increases of up to 120 and 300 percent respectively compared to control plots with no compost. The combination of compost with other WH techniques, such as zai, micro-irrigation or stone lines, can substantially increase the effectiveness of this technique in augmenting yields. By increasing yields, this technique also contributes to farmer revenue increases.

Grass Strips

Grass strips are commonly used as vegetative barriers to minimize soil erosion and improve infiltration (see Figure 8). They can filter sediments, mitigate excess runoff, and reduce flooding (Knoop *et al*., 2012). Grass strips of between 0.8 - 1 m in width are grown along contour lines on gentle slopes of 2 percent. Common grass species used are, *Andropogon gayanus, Cymbopogon schoenateus, Vetivera nigritiana*, which are sown before the rainy season. The principle is the same as stone lines and earth bunds, whereby the grass strips slow runoff by increasing surface roughness and improving water infiltration into the soil, whilst also gathering fertile soil sediments.

Figure 8: Grass strips integrated with contour furrows to improve infiltration

(Source: M. Gurtner, GIZ, 2008)

Geographical suitability: Grass strips are normally practiced in the Sudano-Sahelian zones where the average rainfall per year ranges between 400–1 000 mm. Although this technique is more popular in sub-humid regions of the country where the climate poses no constraints to grass growth, it is potentially applicable in all agro-climatic zones. It fits both small- and large-scale intervention scales and is adapted to all soil types. Nonetheless, grass strips are particularly suited to non-rocky areas with higher precipitations.

Technical & Environmental factors: Grass strips significantly improve soil moisture in the root zone. The biological barrier slows down water flow, allowing a significant proportion of the water to infiltrate and recharge any underlying shallow aquifers. The adoption of grass strips has a very positive impact on soil quality and the reduction of erosion.

Socio-Economic factors: This is the cheapest and least labour-demanding type of contour intervention across the slope. In case of permanent grasses, the maintenance implies cutting the grass several times per year. In case of annual species, the grass strips have to be re-established every year. In general, experience shows that farmers master the technique quite well as there is no need for specific knowledge or skills. Impacts on women are quite positive, as the grass also provides livestock fodder and a source of income.

Productivity and profitability: The impact of grass strips on yields, without the application of organic soil amendments, remains negligible. Nonetheless, if combined with fertilization, yield increases may be consistent, although there is some risk of competition between the grass and the adjacent crop for water and light. The straw obtained from grass strips can be used to produce seccos or livestock fodder for sale.

Mulching

Mulch is applied to soil as a protective layer to manage the microclimate (see Figure 9). Mulch can be organic material (wood, hay, leaves, needles, shells) or artificial (plastic, geotextile). Different mulch types serve different purposes in different locations. In general, mulch is used to reduce water loss through evapotranspiration, reduce weed growth, protect against heat and cold, and to add soil nutrients. Organic mulch in particular creates ideal conditions for beneficial microbes and insects (e.g. earth worms) that improve soil quality, while discouraging other insects such as slugs.

Geographical suitability: According to CILSS (2012) mulching is suitable in the northern sudanian and sahelian zones (with rainfall of 300-900 mm/year). It suits any type of soil, except flooded soils, and is mostly beneficial to bare, degraded and crusted soils. Woody mulch is practiced in all agro-ecological zones, but the practice is most common in the Central Plateau (in the north sudanian zone). Woody mulch is practiced on many soil types and under various environmental conditions. It is often used for the recovery of bare and crusted soils typical of the sahelian zone ("zipelés" soils).

Technical & Environmental factors: The application of mulch in semi-arid areas of the Sahel, where wind erosion is strong, results in accumulation of sediment particles under the mulch (Mando and Stroosnijder, 1999). Mulching also entails the re-establishment of vegetation in the first year of application (Mando *et al*., 1999). Within two years, mulch may allow the development of a layer of vegetation on bare soils. This improves soil fertility and soil porosity thus its water infiltration capacity.

Figure 9: Mulching with crop residues

(Source: L. Bunclark, 2012)

Socio-Economic factors: Implementation cost is 22 000 FCFA/ha. Labour requirements are 1.5 persons/day/ha. Straw requirements for mulching are 2 t/ha/year (GIZ, 2008). The practice does not require specialized skills. It is, however, necessary that producers have some knowledge in efficient mulching techniques - technical management of trees/shrubs (coppicing, pruning, thinning, etc.).

Productivity and profitability: According to producers of Boulkiemdé Province, the use of neem leaves as mulch doubles crop yields (CILSS, 2012). With stone lines alone, grain yields of millet are on average 266 kg/ha, compared to 395 kg/ha for stone lines combined with mulching. It is estimated that the difference of 129 kg is a result of mulching (GIZ, 2008). The combination of mulching with zai and half-moons can increase yields of rain-fed crops (in terms of both grain and straw).

Water Harvesting from Roads

Water harvesting from roads offers a wide range of possibilities in the country, depending on the objective that one wishes to achieve. In Burkina Faso the most common practices associated with WH from roads are borrow pits and road embankments. These structures, if well-constructed, have a lifespan of 30-50 years when minimum maintenance is assured. The geographical suitability, technical and environmental factors, socio-economic factors, and productivity and profitability factors related to WH from roads in Burkina Faso are comparable with those in Uganda, outlined in the previous section.

Half-moons

Half-moons (or demi-lunes) are small bunds in the shape of a half-moon with their tips on the contour line. The pond inside the demi lunes collects water runoff from the slope (Knoop *et al*., 2012). This technique is used for various purposes such as, to recover rangeland, stimulate tree production and crop cultivation, as well as to increase fodder production (Knoop *et al*., 2012). Half-moons act as a micro-catchment collecting and transporting water to the cropping area that is placed in the middle of the pit, as shown in Figure 10.

Figure 10: Example of demi lunes planted with sorghum

(Source: Meta Meta)

Geographical suitability: This technique is distributed in the regions of the Sahel, North, Central-North. Adapted to the Sahelian, south-Sahelian and North Sudanese climates, earth-made half-moons are not suited to areas affected by heavy rains as they may cause waterlogging and asphyxiation of plants, which can reduce yields of crops that are sensitive to excess water. In this case, stone half-moons are preferable. They are used on degraded and crusted soils. In fact, soil degradation and crusting are the main reasons for the establishment of half-moons on degraded slopes and plateaus (not in the valley bottom) with low to medium slope. Half-moons are also often used on rainfed land by farmers. (CILSS, 2012). According to GIZ (2008) half-moons are designed for agricultural, pastoral and forest lands.

Technical and environmental factors: Half-moons improve infiltration and mitigate the effects of rainfall variability on agricultural production. This technique also contributes to the regeneration of degraded lands, the stabilization of soils and the reduction of water-based soil erosion. It has been noticed that half-moons also help increase the soil organic matter and the availability of nitrogen and phosphorous for plants. Sylvo-pastoral half-moons contribute to a re-greening of the environment and promote biodiversity

Socio-economic factors: The cost related to the implementation of the technology is 50 000FCFA/ha (CILSS, 2012). According to GIZ (2008), labour requirements are 50 people/day/ha for marking the contour; tracing the contours of staggered half-moons; digging micro-basins; constitution of the bund downstream of the micro-basin; supply of organic manure (about 1 tonne per hectare per year). Their implementation allows farmers to resume agro-silvo-pastoral activities on land considered unsuitable for production.

Productivity and profitability: In terms of profitability, half-moons offer the greatest benefits among analyzed WH techniques. The IRR (internal rate of return) of the half-moons is approximately 90 percent considering grain yield and 145 percent if we take into account crop residues (CILSS, 2008). When they are implemented on abandoned land, the yield gain amounts to up to 180 kg/ha of extra millet grain and 400 kg/ha of straw per year. Where forest half-moons are implemented, the annual timber production at the age of ten years is on average one cubic meter/ha. The value of this production can increase to about 850 000FCFA per hectare from the fifth year onwards.

Morocco

The MCA for Morocco evaluated the 13 most common and effective WH techniques in the country, as outlined in Table 3. Performance of the techniques was found to range from 70 percent to 90 percent, with almost half of the WH techniques scoring above 80 percent. The standard deviation of criteria scores varied greatly between techniques. The top five performing WH techniques were spate irrigation (also known as Faid or Ouggoug), bench terraces, WH from roads, micro-basins, and conservation agriculture; their associated scores are shown in Table 6.

In Morocco there is high interest and potential in revitalizing runoff and floodwater harvesting in semi-arid and desert regions. Faid/Ouggoug floodwater harvesting systems scored highly in the MCA and are often associated with high value date palm cultivation. Another high scoring technique, popular in the Rif and High Atlas regions of Morocco, is bench terraces. Bench terraces are particularly suited to regions with steep slopes due to their resistance and effectiveness in controlling erosion compared to other kinds of contour lining systems, such as banquettes. Although the overall score for these two techniques was high, available

Table 6: MCA results for top five performing WH techniques in Morocco

WH technique	Criteria				Weighted performance score
	A	B	C	D	
Spate irrigation/ Faid/ Ouggoug	2.57	4.33	3.63	4.67	90%
Bench terraces	2.83	4.00	3.31	5.00	90%
WH from roads	4.83	4.00	3.50	4.00	87%
Micro-basins	3.50	3.83	3.56	4.33	86%
Conservation agriculture	3.14	3.83	3.00	4.33	82%

data showed great variability in results across the four criteria. Moreover, spate irrigation is largely confined to the arid environments of Morocco and is not very applicable to other AEZs. Although bench terraces have greater potential for application across a wider range of AEZs and show very good results in terms of durability and effectiveness, the construction of new terraces requires a high initial investment, particularly in terms of labour, which may pose a barrier to adoption for farmers. The other high scoring techniques, WH from roads, micro-basins and conservation agriculture, are be more suited for further testing and promotion at a wider scale.

A brief description of each technology and explanation of their allocated MCA scores is provided in the following pages

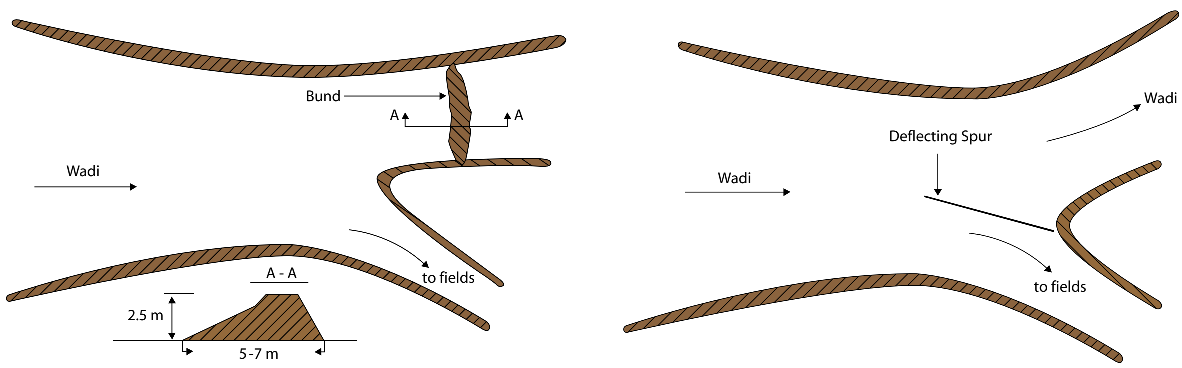
Spate irrigation/ Faid/ Ouggoug

During flood events, water flowing down from mountain catchments is channelled from the naturally dry riverbeds and spread over large areas for irrigation, to fill drinking water ponds, groundwater recharge, improve grazing areas, or a mixture of all these methods (Knoop *et al*., 2012). Unpredictable flood events, which can last anything from a number of hours to a couple of days, are directed to neighbouring land via diversion structures or free intake structures (see Figure 11).

In the arid mountains of Morocco, spate irrigation or dykes in coarse earth (Ouggoug) are built in the main riverbed to divert flood flows into canals and irrigates flatlands downstream. These dykes are generally 1–2 m high with the capability to resist severe floods of a 10 year return period. The floodwater is first transported into a canal where sand and lime are deposited on the floor-bed, and then into tributary canals that distribute water to fields. The water is generally still rich in sediments, making it perfect to use to irrigate and fertilize fields.

Geographic suitability: The technique is adapted to dry desert areas (where rainfall <300mm/year.) In Morocco, this technique is spread in the south, pre-Saharan side of the High Atlas (Tafilalt, Ouarzazate, Tata, etc.) where rainfall does not exceed 200 mm, but this technique could be extended to all arid mountains and foothills around seasonal riverbeds. Water supplies are as short and uncertain as the rains, therefore impacts on agricultural productivity are also highly uncertain (Roose *et al.*, 2010).

Figure 11: Diversion bund intake (Left); Deflecting spur-type traditional intake (Right)



(Source: Sawadogo et al, IUCN, 2011)

Technical and environmental factors: Spate irrigation leads to soil moisture conservation in the root zone and the increased infiltration capacity. If it is currently difficult to quantify precisely the amount of water gained by artificial recharge, but it is well established that farmers observe an increase in the groundwater level after each flood. The adoption of this technique also has a very positive impact on soil quality, particularly by reducing water erosion, and increasing moisture and nutrient levels in soils (WOCAT, 2011).

Socio-economic factors: Training and good organization of the beneficiaries is required. According to WOCAT (2011) the level of technical knowledge of farmers and agricultural extensionists must be high. The diversion structures are often damaged and/or carried away downstream by the violence of the floods. Reconstruction and maintenance are very burdensome and require collective action by the community. Elaborate local regulations and organization and cooperation between communities are prerequisites for the successful management of flood irrigation.

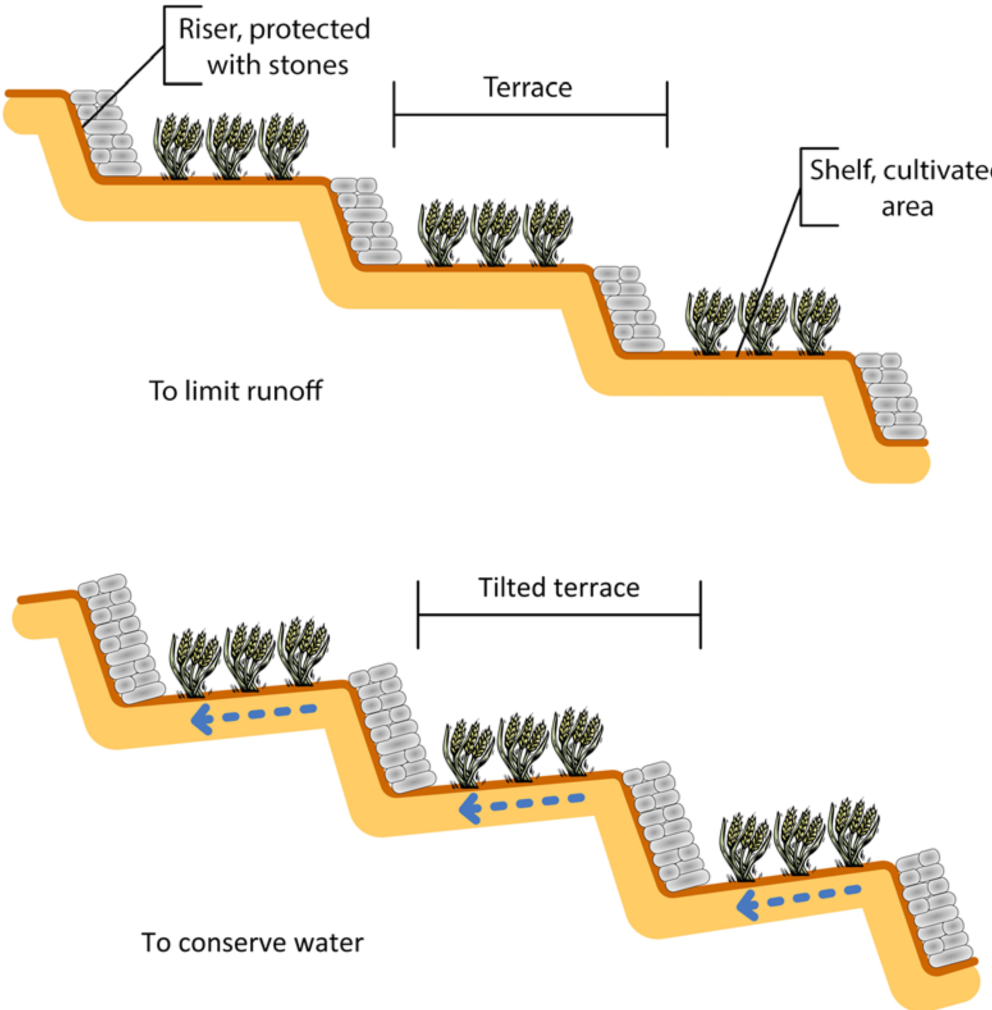
Productivity and profitability: Improving the productivity of gentle sloping land at the foothills by the contribution of sediments and increased yields are direct results of the adoption of the technique. The water seeps deep into the soil and provides enough moisture for crops for 2-3 years for rain-fed crops. Unfortunately, the duration and timing of floods are not predictable and as a result production levels also vary. The profitability of this traditional technique is generally high in the Anti Atlas region, thanks to the combination of various techniques (terraced fields, seguias faid, ouggoug), which mean that farmers have the opportunity to engage in relatively water intensive cash crops that they could not grow without these techniques. However, the construction and operation of infrastructure should fall under the responsibility of the state, in order to make the system profitable.

Bench Terraces

Alternating series of 'shelves' and 'risers' characterize bench terraces (see Figure 12). They are usually developed on relatively steep slopes (15-55 percent) with deep soils that allow this type of landscaping. The alternating flat surfaces are capable of stopping runoff and increasing water stored in the soil profile. In bench terraces the riser is often reinforced with stones and/or vegetation cover. When the shelf is made slightly inward sloping, water storage increases and soil protection is improved. In arid areas, conservation bench terraces are preferred. In such cases, the distance between terraces is increased and a portion of the sloping land is left to act as catchment area. The runoff generated by the catchment area will nourish the plants placed immediately above the riser wall. This design increases the amount of water available for the plants and reduces erosion.

Geographical suitability: According to Roose *et al.,* (2010) ideal climatic conditions for the implementation of bench terraces are annual rainfall of 600 mm, depth of soils of 80 cm, high soil permeability, and a maximum slope of 40 percent (embankment consolidated with stones). Bench terraces are observed both in the Rif and in the High Atlas regions. This type of technique works well on slopes with consolidated and permeable soils. It should never be used on impermeable and friable soils (schist and marl) where risks of landslides are high. Mediterranean bench terraces (with low walls) are found throughout wetter areas, but in arid and semi-arid areas only near springs and seasonal riverbeds.

Figure 12: Bench terrace to limit run-off (top) and bench terrace with back sloping bench to increase water retention time (bottom)



(Source: Knoop *et al*., 3R Water Secretariat, 2012)

Technical and environmental factors: Bench terraces reduce water erosion across the slope, reduce river peak flows and siltation of dams. By reducing runoff, these structures are more effective in controlling gully erosion as continuous banquettes that could overflow. In addition, bench terraces promote accumulation of organic matter and nutrients in the soil. They improve soil productivity through the capture and retention of organic particles transported by water.

Socio-economic factors: Generally the implementation of a terrace requires 350 - 1500 days of work per hectare depending on the type of wall (earth or stone) and the slope (Roose *et al*., 2010). Regarding the maintenance capacity, because bench terraces are a traditional technique with high added value (the soil becomes more profitable in time), farmers have guarded a know-how from generation to generation. However, for terraces requiring a higher investment, farmers may rely on external labour where it is not available within the family. To maintain the efficiency of terraces, regular maintenance of the low wall, especially after each major storm, is required.

Productivity and profitability: Improving land productivity is a motivating factor for the implementation of these structures, particularly in semi-arid areas and on steep slopes (that would otherwise be uncultivated due to water erosion). Organic manure and mineral supplements are applied on bench terraces to sustain the production, which helps to produce vegetables in rotation with grain and fodder. Irrigation, vegetable gardens and fruit plantations ensure high profitability of this technology

Water harvesting from roads

As mentioned in the section on WH from roads in Uganda, roads can be a useful mode of water collection and offers a wide range of possibilities in the country, depending on the objective that one wishes to achieve. Examples of this technique can be found across Morocco as micro-basins around trees capture runoff drained by roads and paths. Other techniques are used more specifically in particular areas. In arid and semi-arid zones, runoff from roads is used to recharge matfias, water storage ponds and tanks. In the Eastern Rif and High Atlas regions, water from roads is often channelled to olive and almond orchards, a technique called R'foussi in Berber. In sub-humid and humid areas (Western Rif), excess water drained from terraces is channelled to cobbled cattle tracks that drain water to plots downstream.

Technical and environmental factors, socio-economic factors, and productivity and profitability factors related to WH from roads in Morocco are comparable with those in Uganda, outlined previously.

Micro-basins

Micro-basins are surrounded by earth bunds disposed in form of demi-lunes or in a V shape. The bunds can also be reinforced with stones as shown in Figure 13. Micro-catchments are mainly used for growing trees or bushes. This technique is appropriate for small-scale tree planting in any area which has a moisture deficit. Besides harvesting water for the trees, it simultaneously conserves soil. In the desert and arid steppe and plateaus, ditches are dug at the foothills to collect runoff to irrigate fruit trees (date palm, olive and almond) planted in the best lands of the valleys (deep soils). In semi-arid mountains, on irrigated slopes, micro-basins are associated with various crops (trees or cereals, vegetables and fodder). On dry slopes, natural rangelands are compounded with planted fodder shrubs planted in half-moon micro-basins.

Technical and environmental factors: A single basin can increase the humidity in the soil by about 5 percent and store about 150 mm of water per year. In terms of soil fertility, the micro-basin increases the amount of organic matter in the soil and the quantity of nutrients in the top soil, such as available phosphorus and potassium by an average of 20 percent. Micro-basins also capture sediments and animal waste transported by runoff, thus protecting hydraulic infrastructures downstream (Oukabli., 2012).

Figure 13: Olive tree plantation using demi-lunes to capture runoff from the slope in the eastern Pre-Rif

(Source: Meta Meta.)

Geographic suitability: This technique is adapted to arid and semi-arid areas with an annual rainfall of no more than 500 mm/year and slopes of less than 5 percent. A soil depth of greater than 30 cm and with average permeability is also recommended. As such, earth micro-basins are less appropriate in the sub-humid zones of Morocco, because they do not drain and water may stagnate at the root of plants. In this case, a stone wall around the micro-basins should ensure adequate drainage. This type of structure is also better adapted to the more accentuated slopes of the Rif region.

Socio-economic factors: Implementation costs range between 15 and 20 Dm (i.e. 1 500 to 2 000 Dm for a density of 100 trees/ha). Micro-basins require regular maintenance, especially to inspect and repair any bunds which may be breached by heavy rains. It is also necessary to keep the basin free of vegetation (weeding) and apply an adequate amount manure to improve crop yields. Overall, micro-basins are relatively cheap to construct, easy to maintain. Moreover irrigation of trees by irrigation channel does not pose problems. This technique is one of the best mastered by Moroccan farmers.

Productivity and profitability: The amount of water retained and stored by the micro-basin can be used to improve the crop water balance, which can lead to yield increases up to 100 percent (the case of olive tree, (Oukabli, 2012)). Regarding the diversification of production, the presence of micro-basins allows the production of fodder crops, cereal crops and orchards. It is not suited for vegetable crops (Roose *et al.*, 2010). Olive trees, almond, apricot, fig, pomegranate are often planted in basins where runoff flows over from basin-to-basin in cascade (El Amani, 1983). Trees are sometimes intercropped with winter cereals

Conservation agriculture

Conservation Agriculture is a farming approach that comprises three principles to mimic natural ecosystem processes: (i) minimal soil disturbance, maintained by planting crops in untilled soil by opening a narrow slot, trench or band of sufficient width and depth that is just enough to achieve proper seed coverage; (ii) permanent soil cover by mulch, crop residues or cover crops; and (iii) crop rotation (see Figure 14). Conservation agriculture favours soil moisture retention, decreases evaporation losses and therefore augments rainfall use efficiency.

Figure 14: Inter cropping with maize and French beans

(Source: MetaMeta, 2015)

Geographic suitability: In Morocco, successful projects in conservation agriculture are found especially on the plains of the regions of Chaouia, Abda, and Doukkala. Brown soils - found on the Atlantic plains, terraces and slopes connecting terraces and eroded hilltops in the Rif area - are well suited for conservation agriculture because of their great agricultural potential and vulnerability (fragile and erodible soils). In the West Rif, Roose *et al*., (2010) proposes the following cultivation techniques: coarse contour ploughing and manure on fallow land, direct seeding on crop residues, spontaneous vegetation cover and cover crops. Traditionally, conservation agriculture is poorly suited to areas where water is a limiting factor and where the provision of permanent soil cover is a problem because of competition for crop residues between mulching and livestock feeding.

Technical and environmental factors: It has been widely reported by many authors that conservation techniques based on direct seeding increase soil moisture content in comparison with conventional techniques. The crop residues and spontaneous vegetation limit evaporation from the soil and maintain soil moisture. Direct seeding reduces erosion and soil compaction while keeping its moisture; water and wind erosion are reduced by 50-90 percent (Moussadek, 2012). The soil and sediments that would otherwise have been lost are rich in nutrients. Conservation agriculture also stimulates biological activity in the soil and reduces surface crusting.

Socio-economic factors: By reducing the use of mechanized labour, conservation agriculture allows a reduction in labour and energy costs. However, herbicide costs often increase. Additionally, high investment costs are required to purchase a combined direct seeder (US$ 6 000), which is seed-specific and so farmers would normally need two separate machines for a corn-wheat rotation. The technique requires a long-term approach to see the benefit of its application. Adoption can be challenging for farmers, as it involves expertise and technical knowledge - a new system for managing crops/soil, new equipment etc.

Productivity and profitability: The implementation of conservation agriculture stabilises yields to levels comparable to modern intensive agriculture practices. During dry years, production under conservation agriculture is generally less affected than under conventional farming. Application of crop residues and crop rotations lead to higher soil fertility levels and thus a reduction in the need for mineral fertiliser. Yield increases with conservation agriculture may range from 10 to 155 percent compared to deep soil tillage, depending on the region of application and rainfall conditions.

Conclusion

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WH holds a great potential in increasing yields and improving food security in rain-fed farming areas such as those found in Morocco, Burkina Faso and Uganda. One important way in which WH contributes to more productive and climate resilient rain-fed systems is by influencing microclimates. By increasing water retention and soil moisture, particularly when coupled with biological measures such as the (re)generation of vegetation and soils, WH has an impact on important processes such as: evaporation, transpiration, air humidity, air and soil temperature, capillary rise, soil microbial activity, soil organic matter build up and decomposition, and plant nutrient availability. If managed well, WH and the microclimates they influence may buffer against climate change and contribute to sustained agricultural production and agrobiodiversity.

WH embraces an extensive range of techniques applicable to various geographical conditions and suited to one or more water uses – domestic, irrigation, livestock, aquaculture and ecosystems. All WH solutions presented here can be used as stand-alone measures, however, if they are combined in a systemic way at the landscape scale, their effect on the overall water buffer is more substantial. Enhancing WH capacity for agriculture therefore requires planning and management of landscapes to meet multiple objectives and stakeholder needs, including agricultural production, livelihood improvement and ecosystem conservation. It is thus critical to know what to do where, how to manage water buffering processes/techniques, how water flows, where it infiltrates, where it can be stored and retained, which type of land cover and land management enhance these processes, and how the micro-climate is affected. Landscape transformation depends greatly on the potential recharge capacity and water storage.

Determining which WH techniques have the best performance and choosing which to promote and upscale requires consideration of biophysical, technical, and socio-economic factors. A main objective of this detailed assessment of WH technologies was hence to guide decisions on the choice of WH techniques to be further tested and promoted based on the context of each of the three countries.

A leading criterion for the choice of WH techniques for upscaling in the three countries is to have a combination of techniques, thus capitalizing on their synergistic behaviour related to their varying impacts on water storage and soil regeneration. Hence, what is suggested here, is to integrate a range of high performing WH techniques that address different aspects of the complex agro-ecological system.

In the three countries it emerges that a combination of measures, rather than stand-alone techniques, is also the most effective way to match the flexibility needed to increase crop production across the range of farming communities present in these regions. Accordingly, the results of these studies suggest the integration of several WH measures in farming systems. In Uganda, storage WH measures – small WH ponds, valley tanks and WH from roads – are suggested for further investigation and upscaling, in conjunction with measures that increase soil moisture such as contour bunds and WH for banana plantations. Similarly, in Burkina Faso, the adoption of grass strips, mulching, and composting should be promoted in conjunction with measures that favour channelling of water from roads and other impervious surfaces to micro basins, such as demi lunes. Finally, in Morocco, given the high geographical specificity of some WH techniques, such as Ouggoug and bench terraces, this assessment suggests that the integration of measures with higher geographical suitability and lower costs is most suitable. Hence, routing and harvesting water from impervious surfaces, micro basins and various elements of conservation agriculture for an enhanced management of soil moisture and soil health are thus suggested in Morocco as a possible combination to increase agricultural production in rain-fed areas.

Looking at the way ahead, what is needed is the promotion of research, experimentation, and outreach to improve, adapt, and spread WH across countries and regions. This can be achieved by increasing linkages between farmers and educational institutions such as universities, colleges and vocational training centers. Experience in Burkina Faso, Morocco, and Uganda, as well as several countries of sub-Saharan Africa, point to one thing: what works is to put the farmer at the center of the process, respecting his/her agency, treating him/her as a client rather than a beneficiary. When farmers are convinced about the benefits of WH techniques to productivity and income, they will take them up, innovate, and adapt them to their specific needs. Many examples show that adoption is not a linear process. On the contrary, it is often step-wise and incomplete, whereby only some elements of suggested technological complexes are taken up; this should not be seen as a failure by implementers and managers of WH systems. Such processes often reflect careful decisions of the farmer based on years of observation of his/her crop production systems and an accurate assessment of his/her own needs and capacities.

In addition to the promotion and implementation of appropriate techniques, the core process of WH development, adaptation, and adoption must also be supported by securing land rights, facilitating access to markets, fostering farmer-to-farmer learning and linking farmers to formal education and research systems. Considering and integrating these and many other institutional enablers in future WH programmes is a fundamental step to creating opportunity for farmer innovation and well-being.

Finally, the emphasis of promoting WH as a means to increase the productivity and resilience of rain-fed farming systems should be on working at scale. One important way to achieve this is to connect WH-related activities with large implementation programs in each country, such as safety nets. This way it will be possible to produce more tangible impacts on the overall water buffer and rural livelihoods.

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Annex I: MCA criteria and indicators

Indicators for Criterion A

Agro-Ecological Zones: The indicator geographic suitability is not an indication of its performance: a low score on geographic suitability - a technique, which works well within a narrow agro-climatic range- does not affect its performance. On the other hand, if a technique is widespread in the country and adapted to a number of agro-ecological zones, this probably means it is also an effective technique.

Uganda

A.1.1 High altitude AEZ

A.1.2 Pastoral, semi-arid AEZ

A.1.3 Northern & Eastern short grassland AEZ

A.1.4 Southern & Western tall grassland AEZ

Burkina Faso

A.1.1 North-Sahelian Zone (Rainfall 350-500mm)

A.1.2 South-Sahelian Zone (Rainfall 500-700 mm)

A.1.3 North-Soudanian Zone (Rainfall 700-900mm)

A.1.4 South-Soudanian Zone (Rainfall > 900 mm)

Morocco

A.1.1 Zone Désertique (Pluviométrie < 100 mm): Pré-Sahara, Sahara, Anti-Atlas oriental, versant sud du Haut Atlas Sud

A.1.2 Zone des Pleines et Plateaux arides steppiques (Pluviométrie entre 100 et 300 mm): Oriental, Souss, Haouz, plateaux atlantiques arides

A.1.3 Zone des Montagnes arides (Pluviométrie entre 100 et 300 mm): Haut Atlas oriental et sud, Anti-Atlas occidental

A.1.4 Zone de grandes cultures des plaines et plateaux semi-arides (Pluviométrie entre

300 et 600 mm): Plaines et plateaux atlantiques, collines du N-O.., Rharb, Doukkala, Tadla, basse Moulouya

A.1.5 Zone des Montagnes semi-arides (Pluviométrie entre 300 et 600 mm): Haut Atlas central et occidental+ Prérif et Rif Oriental

A.1.6 Zone humide et subhumide (Pluviométrie > 600 mm): Prérif, Rif occidental et Moyen Atlas

WH technologies that are potentially applicable in a variety of AEZ received a higher score.

Indicators for Criterion B

B.1 Storage type

B.1.1 In-situ (soil moisture)

B.1.2 Ex-situ (reservoir)

B.1.3 Groundwater

The indicator "Water storage" is a measure of the potential of each WH technology to increase the water buffer at landscape scale. In other words, its contribution to the hydrological cycle.

The 3 sub-indicators correspond to the impact of the WH technology on the water buffer, that is, the type of storage they entail:

- Soil moisture conservation in the root zone (= how much does the WH technology contribute to increasing soil water retention capacity)
- Water storage in an open or closed reservoir (= how much does the technology contribute to the recirculation and storage of water in a reservoir for subsequent multiple uses)
- Recharge and storage of water as groundwater (=how much does the technology contribute to the infiltration of water below the root zone to recharge the aquifer)

B.2 Storage capacity

This indicator measures the volume of water that can be stored by a specific WH technology. This indicator applies only to water storage in open or closed reservoirs.

B.3 Soil quality

It is a measure of the positive impacts of each technique on soil properties (physical, chemical, biological) and against soil erosion.

Indicators for Criterion C

C.1 Multiple uses of water

C.1.1 Irrigation

C.1.2 Livestock

C.1.3 Domestic

C.1.4 Environmental

This indicator measures the use of water stored by a certain WH technology. Techniques that contribute to more uses received a higher score.

C.2 Costs

This indicator considers investment, operation and maintenance costs (often expressed in labour requirements) for each technique and attaches a lower value to those techniques having higher costs.

C.3 Management and maintenance capacity

This indicator provides information on the availability of local expertise and capacity to maintain and manage the techniques.

C.4 Gender

The gender indicator is a qualitative assessment of the implications of the different technologies for both men and women. For instance, techniques that increase workload of women or favour men more than women score lower.

Indicators for Criterion D

D.1 Productivity

This indicator measures the quantitative increase in crop yields compared to control (same crop without the adoption of the WH technology).

D.2 Diversification

This indicator measures the extent to which agricultural production can be diversified (also introducing higher value crops) thanks to the adoption of the technique.

D.3 Profitability

This indicator informs on the relation between revenue obtained or anticipated by the farmer (long-term) and the resources deployed to obtain the revenue (cost-benefit).

Strengthening agricultural water efficiency and productivity on the African and global level

Status, performance and scope assessment of water harvesting in Uganda, Burkina Faso and Morocco

The assessment outlined in this report forms part of the 'Strengthening Agricultural Water Efficiency and Productivity on the African and Global Level' project, which aims at reducing hunger and poverty in three African countries (Burkina Faso, Morocco and Uganda) by focusing on the improvement of AWM and mainstreaming AWM in national frameworks and processes. In particular, this report contributes to Output 3 of the project: Enhanced water harvesting capacity for agriculture in Burkina Faso, Morocco and Uganda.

This assessment targets agricultural water extension agents and technical experts, providing them with clear indications on how to improve WH capacity for agricultural production in the three case study countries, as well as how to select feasible and suited WH techniques for different geographical areas. It is an assessment of the status, performance and scope for improving WH for agriculture in the three countries and provides a portfolio of technologies with their suitability and feasible application to countries' conditions.

This report summaries the assessment of 42 WH best practices across the three case study countries using Multi-Criteria Analysis (MCA). Each of the selected WH techniques is already extensively applied or has potential to be applied in Uganda, Burkina Faso and/or Morocco.

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