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Water Harvesting Potential for Africa

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SEVENTH FRAMEWORK PROGRAMME

WATER HARVESTING POTENTIAL FOR AFRICA

AN ASSESSMENT OF COSTS AND IMPACTS

April 2011

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PREFACE

This report forms part of a two part final product of a consultancy project. Its aim is to outline a review on innovative and small scale water harvesting techniques that could be up-scaled and used in the local study sites of the WAHARA project. It also includes country reviews of Burkina Faso, Ethiopia, Tunisia and Zambia and impact analysis of technologies that includes impact indictors and descriptions of cost, advantages and disadvantages.

The project was commissioned by Frank van Steenbergen; owner and director of MetaMeta, and was conducted by 7 Wageningen UR master students over an 8 week course Academic Consultancy Training at Wageningen UR. Dr.ir. Jan de Graaff; (Associate Professor in Land Degradation and Development Group at Wageningen UR) provided expert and academic advice whilst the team process coach was Claudia Hiemstra (Partner in sensible training and coaching at Zinnige Zaken).

We want to thank MetaMeta for the opportunity to execute this project, and the chance to experience consultancy work in a safe environment where we were able to learn and grow. We especially want to thank our commissioner Frank van Steenbergen for his advices during the meetings, his flexibility, and his openness in sharing information. We are also grateful to our supervisor Jan de Graaff for his content advice and extended list of references.

We are grateful to William Crtichley and Pieter van der Zaag for taking the time to be interviewed by us and shared valuable information with us. We would also like to acknowledge the students who were willing to be interviewed by us and who inspired us to get opinions from people who are part of the communities where WHTs are applied; Kudzai Magwenzi, Melivin Naythi, Elvis Mupfiga, Tyrell Chisenga, Svongwa Nemadire, and Yulius Suni.

We are grateful to have had Claudia Hiemstra as our team process and building coach. Learning to connect with one another in a culturally and academically diverse environment was challenging but possible with the guidance of our coach.

Lastly we would like to appreciate the high spirits that were maintained throughout the 8 weeks and the strong motivation that each one of the team members possessed towards completing the project and getting to know one another better.

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ACRONYMS

AEZ: Agro-Ecological Zone

WHT: Water harvesting technique

C: Catchment

CA: Catchment area

C:CA: Catchment to Cultivation area ratio

WAHARA: Water Harvesting for Rainfed Africa

EXECUTIVE SUMMARY

In a context in which the water and food security issue is an ever growing concern, Meta Meta together with other organizations has designed the WAHARA project. The primary objective is to develop innovative appropriate WH technologies for different geographical regions of rain-fed Africa applicable beyond the local study sites (Zambia, Burkina Faso, Ethiopia, and Tunisia). The program is expected to start in May 2011 and as an initial step it is important for the project implementers to have a guiding document that can be used for selecting suitable and appropriate technologies that can be adopted and upscaled both vertically and horizontally in the specific study sites of the WAHARA project. As such, MetaMeta on behalf of the WAHARA program commissioned this research that seeks to assess the viability of local small scale innovative water harvesting techniques for specific African agro-ecological zones with an ultimate goal to provide information for probable up-scaling and adoption of these innovations.

In order to provide answers for the main objective of the research commissioned by MetaMeta, the WUR students' Academic Consultancy Training group, in consultation with several stakeholders set out on a series of steps guided by a set of research questions. Firstly, focus was put on in-country and site specific conditions, that included soils, climatic conditions (temperature, precipitation, evapotranspiration, wind and humidity), topography, socio-economic conditions, and current land tenure systems. Water harvesting technologies inherent in the countries of interest and from other regions with potential to be implemented to the study sites were then assessed. These technologies were grouped into several categories based on certain criteria. Costs of implementing these WHTs per category were assessed with Environmental, social, economical and technical impacts of these technologies being identified. Indicators for these impacts were narrowed down and a set of impact analysis tools were suggested; all as part of an impact assessment toolbox.

To gather relevant information for the consultancy project, an extensive desk based literature study from a variety of reliable sources was done and interviews with two (2) experts and seven WUR African and Asian students were conducted.

The consultancy research showed that several local, cheap and innovative WHTs meant to boost agricultural productivity do exist in different agro-ecological zones. In most cases WHTs are similar in nature but they have been adopted and modeled with time to suit site specific conditions that include climatic and environmental conditions. With this, variations can occur for a particular WHT within the same country or between different regions. It also turned out that it is important to use WHTs in integrated agricultural systems to achieve better results. Furthermore, universal indicators that cut across different WHT classifications or categories can be developed and used to assess the impacts (anticipated or current) of WHTs. These indicators can be used independently or as a part of several methods such as Multi criteria analysis, Cost and Benefit analysis, Stakeholder analysis, Environmental Impact assessment (EIA) and Geographical Information Systems (GIS). Factors such as knowledge sharing between farmers and other stakeholders, land tenure rights, additional benefits apart from improving agricultural production and increasing resilience to climate change were noted to be import in influencing adoption and up scaling of WHTs.

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INTRODUCTION

Recent studies underline the importance of efficient agricultural use of rainfall to improve crop yields and increase food security (Mishra 2006, Nyagaka & AL., 2003, Oweis “Water Harvesting for Improved Rain-fed Agriculture in the Dry Environments”, 2009). In Africa, agriculture is often hampered by the lack of easily accessible water resources, low rainfall and often unpredictable rainfall patterns. Small scale farming produces 75% (Nyagaka & al., 2003) of the total agricultural output and of it 90-95% is rain-fed (Rockstrom, 2002).When there are no alternatives other than rain-fed agriculture, water harvesting technologies are often used to increase the available water to the crops. There is historical evidence of their adoption that dates back to 10.000 B.C. and the importance of tapping and using rainwater was clear in the time when no electric pumps existed, no big reservoirs were constructed and piped aquifers were still not in use (Mishra, 2006). Nevertheless, in the modern era this knowledge has partially been fading. However, with the current food and water crisis and with the worries shaded by climate change, the importance of low-cost, local and efficient solutions to water scarcity is being revalued. These solutions including Water Harvesting Technologies (WHT) have been developed and adapted locally to perfectly match the climatic conditions of specific areas. As a consequence their introduction in other areas has been difficult in many instances (Nyagaka & AL., 2003).The WAHARA project tries to locate and review local specific techniques with the hope of upscaling the adoption to the whole African continent.

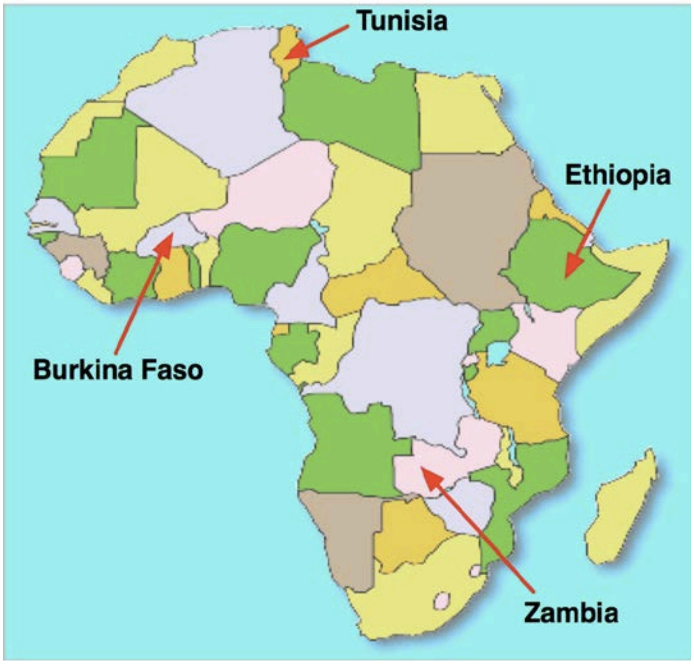


Figure 1: Map showing the four selected countries for the WAHARA project.

Source:

In the WAHARA project, four local sites were selected based on three major factors. First, their geographical spreading (North, South, West and East) in rain-fed Africa. Second, they represent the conditions of the four agro-ecological zones; seasonally humid (Ethiopia), sub-humid (Zambia), semi-arid (Burkina Faso) and arid (Tunisia). The different rainfall conditions in each region result in seasonal drought and/or water scarcity. For instance, in the Mediterranean regions, the annual precipitation (around 300 mm/year) usually fall during the cold season and a big share of it is lost through evaporation and runoff. On the other hand, in the sub-Saharan countries the rains usually come in the warm season and even if they are quantitatively adequate a greater part of it is lost through evapotranspiration (Oweis Water Harvesting for Improved Rain-fed Agriculture in the Dry Environments, 2009. Third, the rural population in the study sites relies heavily on agriculture.To meet the challenge the WAHARA consortium will have to face radically different conditions present throughout the continent. Furthermore, the introduction of water harvesting technologies to reduce water insecurity need to be appropriately selected in accordance with farmers interest. The importance of agricultural traditions, eating habits, social behavior and economic situation of the local communities has to be kept in mind constantly to achieve successful adoption of new technologies. The impact of the techniques might positively affect the agricultural production, the economy and the welfare of the community, but it might also have negative side effects on other users and other ecosystem services.

With this in mind, the ACT task-force, was commissioned by MetaMeta on behalf of the WAHARA project to provide, i) a selected review of suitable and innovative technologies grouped into 9 basic categories, ii) give an overview of their potential advantages and disadvantages (environmental, social, economic and technical), and iii) review a wide range of sources for costs of the techniques with reference mainly to the four researched countries and the regions where they are located. Indicators for the impacts were also developed and form part of this report as well. The report is meant to ease the initial steps of the WAHARA project in finding suitable techniques for the continental up-scaling, iv) A toolbox containing methods to assess the impact.

The main focus of the research reported here, was on low-priced , household or community level WHTs suitable for small scale dry-land agriculture (e.g. Runoff farming). Labour intensive, expensive and sophisticated WHTs were deliberately excluded from the study. Water supply for domestic purposes was also out of the scope of the study, except in cases that a WHT has a double productive use. Figure I below illustrates the parameters that were used to narrow down the different WHTs. The report goes beyond the conventional examples of Water Harvesting to find possible innovations. Special attention has been put on agronomic and management techniques that coupled together with WHTs can enhance the use of precipitations for agricultural use.

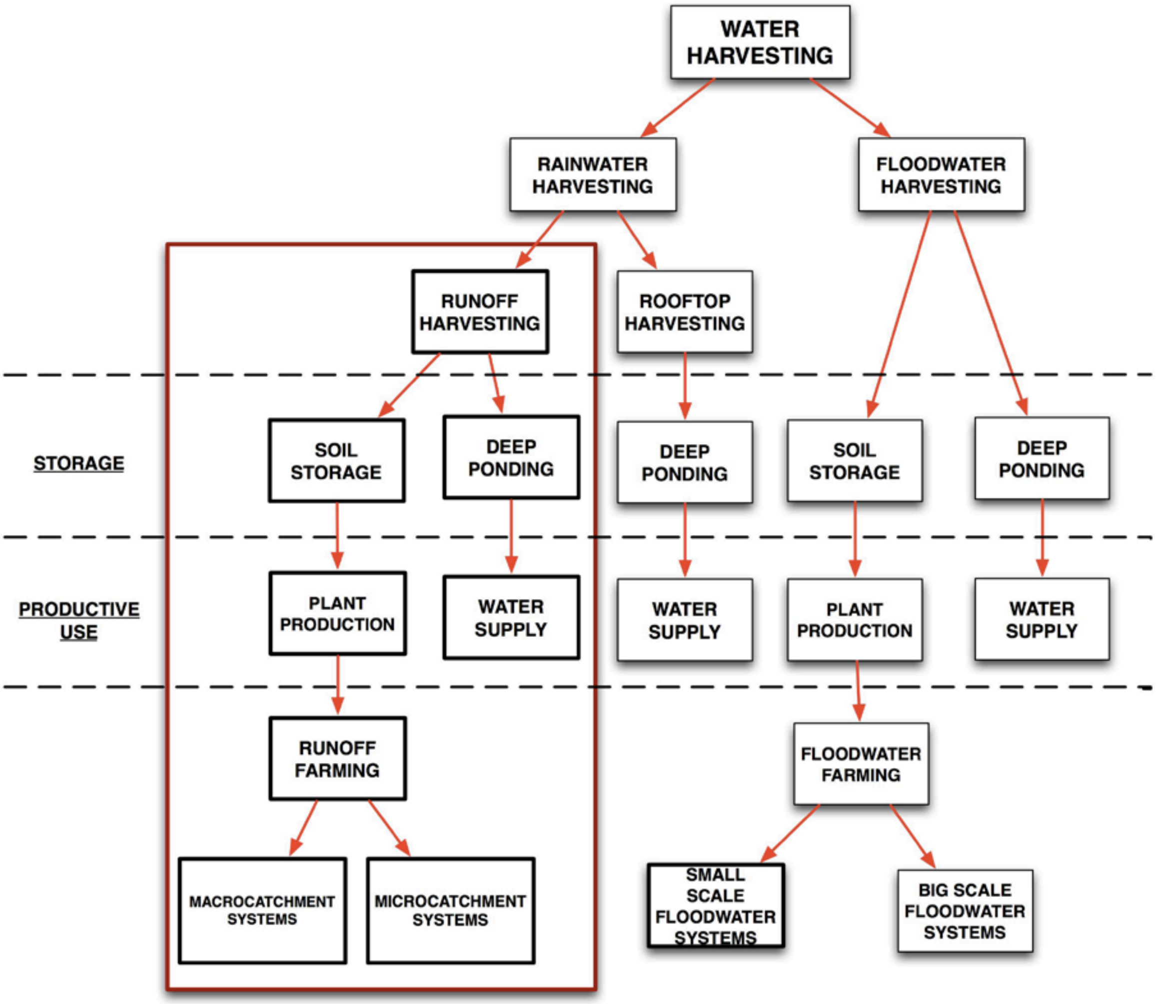


Figure 2: Classification of Water Harvesting techniques according to typology, storage media and productive use. The section delimited with the red box defines the main focus of the project (based on the model of Critchley & Siegert, 1991).

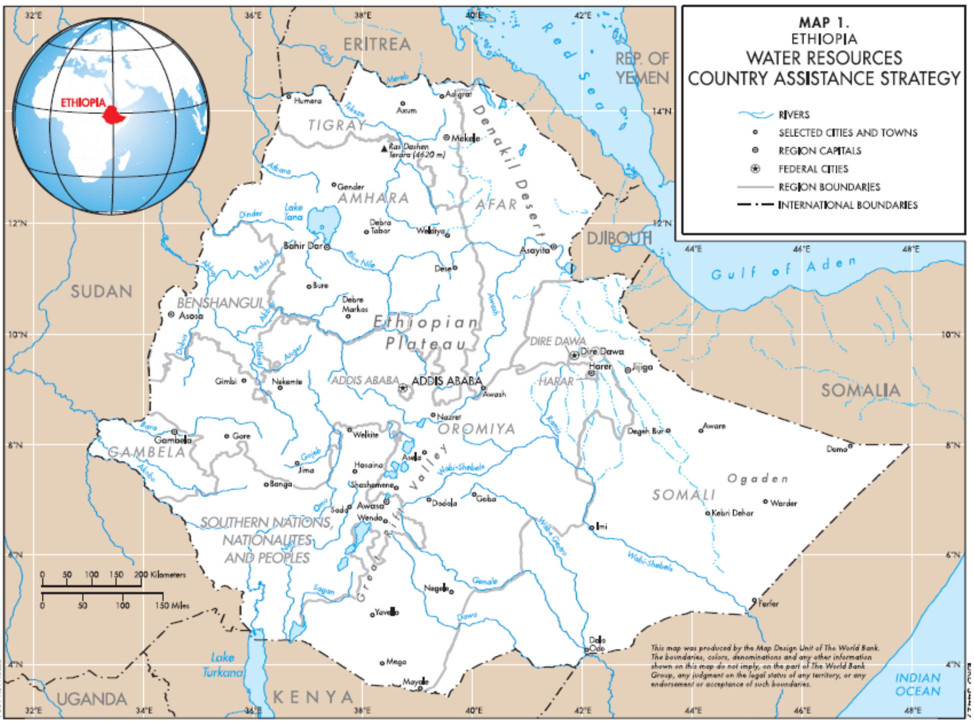
RESEARCH BACKGROUND

A wide range of WHTs can be found at the global scale and they differ substantially from each other in requisites, effects and costs. In order to compile a techniques review that might be considered useful for the project, we first tried to understand what are the peculiarities that characterize the four countries considered in the project. After a first short description of the country as a whole, a more specific account about the specific study sites has been compiled. With this purpose in mind we tried to portrait the areas looking at physical, socio-political, and economic aspects.

Ethiopia

INTRODUCTION

Ethiopia is a landlocked country located in the Eastern Horn of Africa at latitude 3°24` and 14°53` North; and longitude 32°42` and 48°12` East (see Figure 1). It borders Eritrea to the South, Sudan to the East, Kenya to the North and, Somalia and Djibouti to the West (FAO, 2006; Chiche Yeshi 2002; Chnayalew et al. 2009). It is a very vast, agro-ecologically complex country covering an area of 1,120,000km^2 and a population of over 77 million people by 2008 (Chnayalew et al. 2009). According to projections, the population is estimated to reach 81 million by 2011(CSA, 1994, cited in Chnayalew et al. 2009). Seventy percent of the available agricultural land is located between 1800 and 2500 m above sea level and receives an annual rainfall amount of more than 600 mm (Tsegaw, 2006).



[source: World Bank, 2006; the orange circle illustrates the location of the local study site]

Figure 3: Map of Ethiopia with main water resources

The country comprises diverse topographic features such as rugged mountains, flat topped plateaus and valleys ranging from deserts at 125 m below the sea level in the Dankel depression to the highest point at about 4620m above sea level in the Ras Dashen area where precipitation reaches 2800mm. The mean temperature also changes drastically from 45^o C at the lowland to about 0^{o}C in the mountains (Leipzig,1996; Tesgaw, 2006; Chiche 2002; Chnayalew et al. 2009). The topographical differences determine climate, soil, natural vegetation and settlement distribution patterns. About 65% of the land falls under the moist, sub-humid, humid, and per humid agro-ecological zones (Tsegaw, 2006; MoA, 2000 cited in Deressa, 2010). The rest of the land (35%) is arid and semi-arid with high temperatures throughout the year and mainly under either agro-pastoralism or pure pastoralism (Chnayalew et al. 2009; Tsegaw, 2006).

The extreme diversity in topography is one of the causes of the variability of soils in Ethiopia, combined with factors such as climate, parent material, organisms and time (FAO, 1984e cited in FAO, 2006). Nineteen soil types have been identified by MOA (2000) and their distribution in the country is shown in the Appendix.

The climate of Ethiopia is "tropical monsoonal with great topographic-induced variations"(Ethiopia, 2004) .The seasonal migration of Inter-Tropical Convergence Zone is another feature controlling the Ethiopian climate whose cycles follow the position of the sun relative to the earth and the associated atmospheric circulation (Deressa, 2010). The complexity of the climates experienced in Ethiopia has prompted many agro-ecological classifications some of which include the traditional, the Koppen's, the Thornthwaite's, the rainfall regimes and the agro-climatic zones classification systems. The two commonly used classifications are the traditional and Agro-Ecological Zones (AEZ). The traditional classification system is based on altitude and temperature and has grouped Ethiopia into five climatic zones, which are, Wurch (cold highlands), Deaga (cool, humid highlands), Wyena Dega (temoperate, cool sub humid highlands), Kolla (warm, semi-arid lowlands), and Bereha (hot and hyper arid) (Deressa, 2010). Due to variations in elevation and rainfall distribution patterns, they elicit different agricultural production systems with the highlands supporting the most agricultural activities (Dega& Wiena Dega zones) while the arid and semi-arid lowlands (Kolla and Behera) mainly support livestock production systems.

AEZ classification method is based on periods, temperature and moisture regimes and groups Ethiopia into 18 major AEZs, subdivided further into 49 AEZs (Tsegaw, 2006; Deressa, 2010). The 49 sub AEZs are in turn grouped into six major categories according to (MoA 2000, cited in FAO 2006; Deresa, 2010). More details on these two classification systems are presented at the Appendix.

The economy of Ethiopia is highly dependent on agriculture, contributing to about 50% of the Gross Domestic Product, 90% of the annual export earnings and supporting more than 85% of the country's livelihoods (Chiche, 2002).
Mixed farming, including crop agriculture and livestock keeping, constitutes the main farming system all over the country and plays a very important role in domestic and foreign exchange needs. Traditional subsistence crop agriculture is rain-fed with limited irrigation systems. Although small-scale traditional irrigation has been practised for a long time, it has always been possible in "the highlands where small streams are diverted seasonally for limited dry season cropping" (Kassahun, 2009). The country's potential for irrigation agriculture is estimated at 30,000 km^2 of which only 1660 km^2 (640 km^2 falling under small-scale irrigation) is under irrigation (FAO, 2006).

Natural vegetation in Ethiopia is composed of four main biomes, which are found across the country as described briefly below:

a) Savannah: consisting of montane tropical vegetation with dense, forests and rich undergrowth. Drier savannah and tropical dry forests mixed with grassland are present at lower elevations of the Western and Eastern highlands.

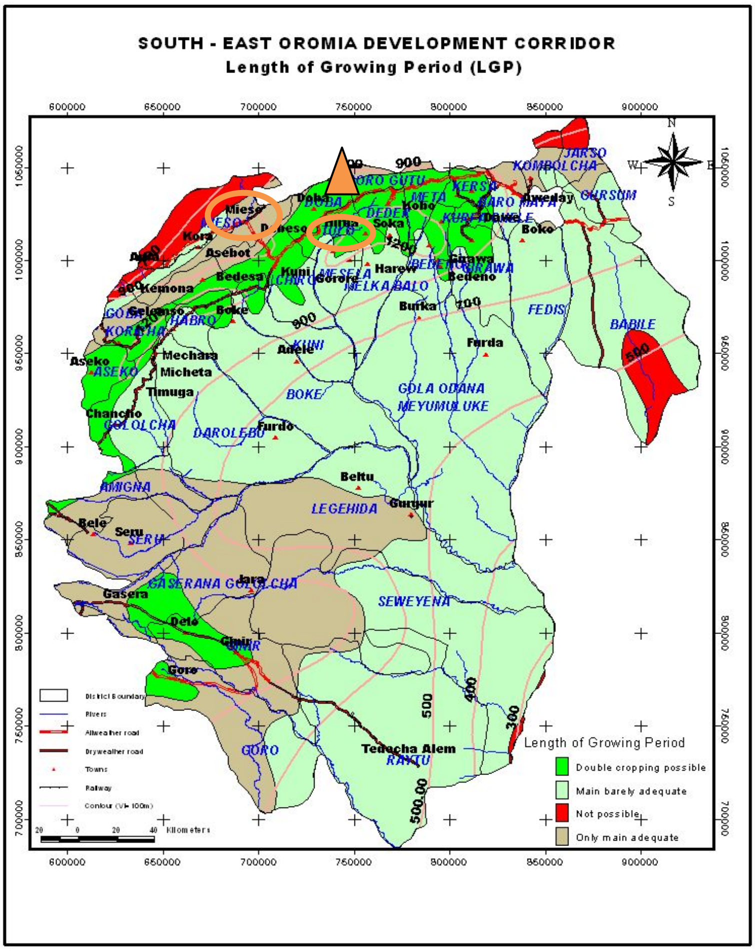
b) Mountain vegetation: mostly montane and temperate grasslands, covering the higher altitudes of the Western and Eastern Highlands.

c) Tropical thickets and wooded steppe found in the rift Valley and Eastern lowlands

d) The desert steppe vegetation in the Dankil Plain (Leipzig, 1996).

In figure 1 the local study site has been circled in Orange, this is the Doba watershed. The next section gives the site conditions.

Study site: Daro Lebu (Hararghe administrative zone)



Source: Regional State Oromia Ethiopia Report 2009 Land Use Valley Irrigation Drainage Water Resource]

Figure 4: *Maps of South - East Oromia with study sites and local metereological station*

Hararhge administrative zone is situated in the Eastern Oromia region, Eastern Ethiopia bordering the Somali region and urban administrative regions of Dire Dawa and Harari (Piguet, F., 2002; Guinand,Y. 1999; Goal Ethiopia, 2003). The overall area of the study site is 1903 km^2.
The altitude varies greatly ranging from 1000-2000 m a.s.l. in Daro Lebu district to 1000-2400m a.s.l. in Quni (Goal Ethiopia, 2003).
The total population in Daro Lebu district (Wereda) is 198,095 (96,499F), with 16, 862 (7,853 F) people living in Daro Lebu town (Central Statistics Agency of Ethiopia, 2007[1]).
In the region, there is a clear division of labour between females and males. Females are totally responsible for reproductive activities and transporting manure to the field. It is the responsibility of men to manage community activities and farm work, but women equally participate in picking coffee berries. Women are

[1] http://www.csa.gov.et/index.php?option=com_rubberdoc&view=category&id=72&Itemid=521

involved in petty trading so as to secure extra cash income especially in times of food shortages. Men also assist in milking, collecting fuel wood among other activities (Goal Ethiopia, 2003).
Women are the busiest. Therefore, if the project is to involve women actively in the programme implementation it should carefully plan its activities to suit their busy schedule and incorporate labor and energy saving technologies to save them time. (see appendix for women schedule)

In 1997 (the population was 136,268, of which 65,659 women), it was estimated that about 5.8% of the total area of Daro Lebu was under cultivation of which 2.8% with permanent crop production systems, 31.1% was under pasture, 0.5 forest and 7.7 under shrubs and brush lands. Increased population pressure has subjected farmlands to extreme degradation. Environmental degradation is severe as a result of this low level of subsistence agriculture with the land being stressed and thus the communities living in the region have become highly vulnerable to effects of drought and other catastrophes. (Goal Ethiopia, 2003)

Figure 5: *Farmland expansion into very steep slopes (Goal Ethiopia, 2003)*

At higher altitudes, the economy is based on both food and cash crop production. The main staple food is sorghum, and maize and sometimes potatoes are grown to cushion from food insecurity especially in times of low rainfall amounts. The main cash crops include chat, a popular mild narcotic, whose demands exceed the actual production capacity, coffee, Irish potatoes, and onions. The production of these cash crops is concentrated in the Weyna Dega and the lower Dega. Chat can also be grown in Kolla. Over the years most of the production has been geared towards subsistence farming but the current trend is focused on cash crop production systems (Guinand, Y.,1999).
At the lower altitudes, crop production is usually limited, rendering it as suitable for livestock based economic production systems. (Guinand, Y.,1999)

<u>SOIL AND TOPOGRAPHY:</u>

There is a variety of soil types in the study area of which up to nine soil groups were identified. However, Euric Cambisols (31%), Vertic Cambisols (24%) and Leptosols (24%) cover the largest portion of the region. In some areas such as Hirna the soil has an aggregate stability of up to 70% while for Vertisols, the aggregate stability falls between 50-70%. They are black with a swelling ability characteristic. Some soils exhibit no free lime and contain more than 50% rock fragments, enabling the formation of narrow v-shaped gullies. Farmers use stone terraces and bunds, oxen for ploughing along the contours to prevent erosion (Bobe,B.W, 2004).

The major crops grown in the region are sorghum, barley, wheat, beans, sesame, haricot bean, groundnuts, teff, maize among others. For more information see the appendix 3 (MOA, 2000).

Common vegetation types falling under these ecological zones include bushed shrub-grasslands, exposed rock surface with scattered grasses and open shrub lands. Vegetation types under these vegetation types are Juniperus, Hagenia, Podocarpus, Arundinaria, Acacia, Cordia, Ficus, Millettia, Cyathea, Albizia and Erythrina (MOA, 2000).

In this region, land is state owned property and farmers have only usufruct rights on land allocated to them by the local authorities. There is a possibility to access additional land for cultivation through fixed rent tenancy and sharecropping (a land rental system) or land borrowing, gifts. Population pressure has constrained the size of land one can own or borrow thus resulting into very small individual farm units that are uneconomically viable. The farmer's access to such facilities as credit, market integration and effective advisory services plays a big role in his ability to access land (Belay, and Manig, 2004).

CLIMATE:

The highland region of Hararghe is the only area with climatic conditions that can support rainfed agriculture.

Rainfall exhibit bimodal distribution pattern with the short, "belg" falling between March and May and the main "meher" (June-August) seasons. During belg, production is limited within the Dega belt and part of the wetter Weyna dega. Belg rains are used widely for land preparation in expectation for the long rain season of meher crop production. Yearly rainfall distribution and frequency is highly variable resulting in a wide range of climatic hazards (Goal Ethiopia, 2003, Guinand, 2000; Guinand, 1999).
The study area falls under the last three climatic zones based on traditional classification systems viz. Dega (0.5%), Weyna Dega (34%) and Kolla (66%) whose characteristics are shown below as:

***Table 1**: Climatic zones for Hararghe*

Zone	Altitude (m)	Mean annual Rainfall (mm)	Temperature (°C)	Crops/land-use
Weiner Dega (Temperate, cool sub-humid, highlands)	1500-2300	800-1200	20-17.5/16	Teff (most of the population lives here)
Kolla (warm, semi-arid lowlands)	500-1500	200-800	27.5-20	Sorghum, corn, teff-moist
Bereha (hot and hyper-arid)	<500	<200	27.5	Pastoralism

For more detailed information about the specific stations climate data consult the appendix 6

AGRO-ECOLOGICAL ZONES:

The Hararghe administrative zone consists of three agro-climatic zones: (see appendix for a description of Ethiopia's Agro-ecological zones)

***Table 2**: Agro-climatic zone*

Agro climatic zone	Percentage of area (%)
1. Kolla (Lowlands)	35
2. Weyna Dega (midlands)	40

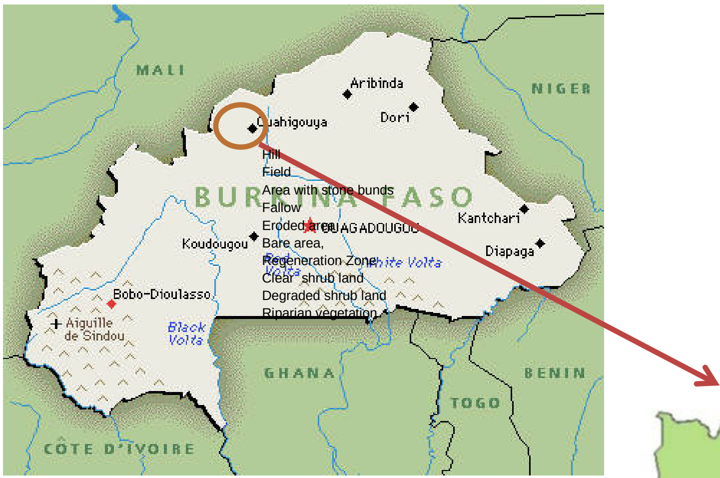
3. Dega (highlands)	25

[Source: Goal Ethiopia, 2003]

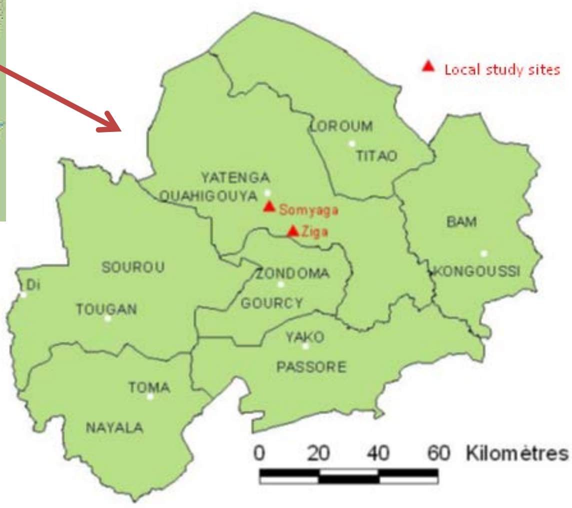
Burkina Faso

INTRODUCTION:

Burkina Faso is a land locked country located in the West of Africa (Latitude 9° 20' and 15° 5' North, and longitude 2° 20' East and longitude 5° 30' West) with a total area of 274,200 km^2. It is bordered by six countries: Mali to the North, Niger to the East, Benin to the South-east, Togo and Ghana to the South, and Ivory Coast to the South-west. The map below shows the neighboring countries and the positioning of the local study sites.



[source: http://topnews.in/law/files/burkina-



[source: http://www.teledetection.net/upload/TELEDETECTION/pdf/20081008134105.pdf]

Figure 6: *Map Of Burkina Faso and The Local Study Site*

The study sites are located in the Northern Province of Burkina Faso; Yatenga Province. This province constitutes about 4.5% of the total Burkina Faso area (12,300km^2)(Bobe, 2004). The first study site, Ziga is located at longitude 1°43' W and latitude 13°06'N with an altitude of 281 m. The second study site, Somyaga is located at longitude 2°55' W and latitude 14°26'N with an altitude of 317 m. According to the Institut National de la Statistique et de la Demographie (INSD) the overall population of Burkina Faso is 15 730 977 (2010) with an average population density is 51.6 people/km^2 (INSD 2006). The annual population growth rate is 3.4% and in 2020 the population projection is 21,510,181. In Ziga the total population is 5,000 and in Somyaga 3,900 (WAHARA report). Burkina Faso is an ethnically diverse country, 40% of the population is part of the ethnic group Mossi, while the other 60% is composed of the Bobo (the second-largest ethnic group (about one million)),the Gurunsi, Senufo, Lobi, Mande, and the nomadic Fulani or Peul.

In general, Burkina Faso is located in the semi-arid agro-ecological zone; it has a dry tropical climate and has two main bio-climates; soudanian and sahelian. 71.3% of the country is located in the soudanian region.

However, Yatenga Province is located in the south sahelian zone, which means that it has an average annual rain fall between 400-700mm (Kagone, 2001). The general Burkinabee climate is characterized by two seasons, a long dry season and a short rainy season.

78.5% of the population lives in the rural area (INSD, 2007) and about 90% of the population is involved in subsistence farming (CIA Factbook, 2011). Burkina Faso is one of the poorest countries in Africa, with a total GDP of $20.06 billion. The main cash crops include cotton (It is the largest producer of cotton in Africa), shea nuts, peanuts, millet, sorghum, maize, rice and sesame. Although the country does not have many natural resources there are 5 gold mines which have contributed positively to the economy, in 2009 gold production was 11.73 tons, in 2010 it more than doubled to 25.6 tons and this year there gold production is expected to increase by 32% (Gongo, 2011). The gold mines are expected to decrease the unemployment rate of 77% (2004)(CIA Factbook, 2011) by creating more job opportunities in the mines.

SOIL AND TOPOGRAPHY:

Yatenga Province is an agro-pastoral area. This means that the population engages in both crop and livestock production. "In the lowlands sorghum occupies 85% of planted areas. On the uplands, millet occupies 75 to 90% of the planted area, sorghum [and cow pea] only 5 to 25%, and maize 2 to 3%, being grown mainly in small plots in compound fields"(Some, 2006).
The natural vegetation is arboreous savannah. It is a steppe dominated by combretum and annual grasses (Kagone, 2001)
In both local sites, the soil type is leached tropical ferruginous, with a slope of less than 1% (Sawadogo, 2008). In Sogmaya, the soil surface sandy loam. The locals also refer to the soil surface as zippele (bare soil and crust) in this area the land has been "overexploited by humans, eroded by violent winds and rainstorms, compacted by animals. The earth is covered by a sterile crust."(Ouattara , 2005) In Ziga, the soil surface is mainly sandy with some gravelly soils. (Sawadogo, 2008)

Before 1984, the legal framework of the land management in the rural area was based on customary institutions and was governed according to customary law. The government only played a role in managing protected/classified land. In 1984, the Government introduced the Réorganisation Agraire et Foncière (RAF), the aim was to "develop a private property rights regime for land," (United States Agency for International Development, 2010) regardless of the former customary tenure status. The law ended the power of traditional chiefs and made land attainable through applying for permits and other government-determined rules. The 2009 Rural Land Tenure Law has been based on this. (United States Agency for International Development, 2010)

CLIMATE:

Table 3: *The meteorological data for Ziga*

Latitude: 13.100° Longitude: -0.283° Elevation: 281m

Month	Prc.	Prc.	Prc. cv	Wet days	Tmp. mean	Tmp. max.	Tmp. min.	Grnd Frost	Rel. hum.	Sunshine	Wind (2m)	ETo	ETo
	mm/m	mm/d	%	days	°C	°C	°C	days	%	%	m/s	mm/m	mm/d
Jan	0	0.0	454.0	0.0	24.7	32.7	16.7	0.1	22.0	76.9	1.6	158	5.1
Feb	0	0.0	416.5	0.0	27.6	35.8	19.4	0.2	19.9	75.8	1.6	161	5.7
Mar	4	0.1	192.0	0.7	31.2	38.8	23.6	0.2	25.4	66.4	1.6	195	6.3
Apr	13	0.4	154.8	1.9	33.7	40.8	26.6	0.1	35.7	63.0	1.6	197	6.6
May	47	1.5	76.0	4.2	33.7	39.9	27.6	0.1	47.1	64.6	1.7	204	6.6
Jun	92	3.1	47.0	7.6	31.2	36.6	25.9	0.0	57.9	58.8	1.7	173	5.8

Jul	163	5.3	38.2	10.4	28.9	33.6	24.2	0.0	67.9	57.6	1.7	158	5.1
Aug	205	6.6	37.4	13.0	28.1	32.6	23.6	0.0	73.3	55.3	1.5	144	4.7
Sep	116	3.9	45.9	8.1	28.8	34.1	23.6	0.0	68.4	61.7	1.3	144	4.8
Oct	22	0.7	121.2	2.5	30.3	37.3	23.3	0.1	53.4	73.7	1.2	162	5.2
Nov	1	0.0	369.7	0.2	28.1	36.6	19.6	0.1	34.7	79.8	1.3	155	5.2
Dec	1	0.0	435.3	0.2	25.0	33.1	17.0	0.1	26.9	76.0	1.5	152	4.9
Total	664											2 002	

[source: AQUASTAT, 2011]

From the table, one notices that the months of Jun-Sept experience the most amount of precipitation and the area that year had 48.87 days of rain. The mean average temperature is about 29.3°C and the reference evapotranspiration varies with the highest value in May (205mm) and lowest in Dec (152mm).

Table 4: The meteorological data for Somyaga

Latitude: 14.433° Longitude: -1.083° Elevation: 317m

Month	Prc.	Prc.	Prc. cv	Wet days	Tmp. mean	Tmp. max.	Tmp. min.	Grnd Frost	Rel. hum.	Sunshine	Wind (2m)	ETo	ETo
	mm/m	mm/d	%	days	°C	°C	°C	days	%	%	m/s	mm/m	mm/d
Jan	0	0.0	456.0	0.0	23.9	31.8	16.0	0.3	22.2	77.2	1.6	152	4.9
Feb	0	0.0	431.7	0.0	26.8	35.1	18.6	0.3	19.5	76.8	1.6	157	5.6
Mar	1	0.0	256.0	0.5	30.5	38.5	22.6	0.3	21.5	67.8	1.7	199	6.4
Apr	4	0.1	236.0	0.9	33.6	41.2	26.0	0.2	26.9	64.4	1.7	207	6.9
May	21	0.7	120.2	2.0	34.9	41.5	28.3	0.1	36.8	65.4	1.8	221	7.1
Jun	59	2.0	58.7	6.1	33.0	38.9	27.1	0.1	48.2	58.8	2.2	204	6.8
Jul	121	3.9	46.6	9.1	30.4	35.8	25.0	0.0	60.5	59.8	2.1	183	5.9
Aug	152	4.9	42.9	11.1	29.2	34.3	24.2	0.0	67.2	60.6	1.7	162	5.2
Sep	77	2.6	51.5	6.8	30.2	36.0	24.4	0.1	60.7	64.9	1.6	162	5.4
Oct	15	0.5	142.2	1.8	31.3	38.6	24.1	0.1	42.8	74.4	1.3	173	5.6
Nov	0	0.0	442.8	0.0	28.1	36.4	19.9	0.2	28.9	81.9	1.3	155	5.2
Dec	0	0.0	437.4	0.1	24.4	32.4	16.5	0.3	26.4	75.5	1.5	147	4.7
Total	450											2 123	

[Source: AQUASTAT, 2011]

The table shows that rainy season occurs during the months of May-Sept while Nov-April experience the dry season. During this year the area had 38.4 days of rain. The mean average temperature in the table is about 29.7°C and the reference evapotranspiration varies with the highest value in May (221mm) and lowest in Dec (147mm).

As both areas are located in the Yatenga province they are located in the South Sahelian zone and thus should have an annual average rainfall between 400-700mm, this is the case (Ziga 664mm and Somyaga 450mm). The rainfall pattern also clearly illustrates the two seasons; a long dry and a short rainy one.

AGRO-ECOLOGICAL ZONES:

Based on vegetation and climatic characteristics four agricultural zones have been defined in Burkina Faso. The Northern Province lies in the sub-sahel zone.

***Table 5**: Agro-Ecological Zone of Burkina Faso*

Zone	Percent of national territory	Annual rainfall mm.	Land cover
Sahel	13.4	< 400	· Steppe with thorny bushes and annual grasses · Pastoral zone evolving to agro-pastoralism, mainly pastoral at present · Subsistence farming based on millet, sorghum and cowpea · Transhumant herding
Sub-Sahel	15.3	400 to 700	· Steppe with combretum and annual grasses · Agropastoral, mainly agricultural zone · High population density and land fully occupied · Subsistence farming based on millet, sorghum and cowpea · Transhumant herding and sedentary agropastoral agriculture
North-Sudan	38.9	700 to 900	· Savannas with trees or shrubs · Agropastoral, mainly agricultural zone · High human and livestock population density · Cotton area with agriculture based on sorghum, millet, cowpea and groundnut · Transhumant pastoralism and sedentary village stock raising
South Sudan	32.4	900 to 1 200	· Savanna with trees or shrubs, sparse forests · Agricultural area characterised by perennial crops (mangos, citrus, cashew etc.) cotton growing, yams and cereals (sorghum, millet and maize. · Used by transhumants in the dry season with sometimes mortal conflicts between pastoralists and farmers. · Sedentary village stock rearing of taurin cattle.
NB. Subsistence farming is very widespread; it is essentially manual with very few external inputs. Animal traction is mainly used in the cotton-growing tracts (cash cropping) where modernisation (mechanisation and use of agrochemicals)			

[Source: http://www.fao.org/ag/AGP/AGPC/doc/Counprof/BurkinaFeng.htm#3.%20CLIMATE%20AND%20AGRO%20ECOLOGICAL]

[source: http://www.fao.org/ag/AGP/AGPC/doc/Counprof/BurkinaFeng.htm#3.%20CLIMATE%20AND%20AGRO%20ECOLOGICAL]

Figure 7: *Map of Burkina Faso showing the Agro-Ecological Zones*

Tunisia

INTRODUCTION:

Tunisia is located in the North of Africa, at latitude 34°00'N and longitude 9°00'E. It borders Libya to the North West, Algeria to the East and the Mediterranean Sea to the South (CIA world factbook, 2010). With a total area of 16, 361 km^2 Tunisia is one of the smallest countries in North African, and is also one of the most densely populated countries of North Africa with a population of 10,549,100 (67.0 inhabitants/km^2) (National Institute Of Statistics (INS)– Tunisia, 2010)

The population growth rate has been decreasing over the years, from 2.09% (1999) to 0.98% (2010). The projected total population for 2039 was estimated to be 13,014,000. 65.9% of the population lives in the urban area (INS Tunisia, 2009). Although Morocco has a higher population density, Tunisia's total arable land is lower resulting in a higher population pressure on land. In other words, the rural population (especially pastoralists) needs more ha to keep the same amount of livestock. Despite the (semi-)arid climate and the negative water balance throughout the year, many civilizations have flourished in Tunisia. Tunisia's long tradition of coping and mitigating with water scarcity in the form of water harvesting techniques (WHTs) might have been the reason for this. Archaeology shows that these WHTs go back to antiquity (Ouessar et al., 2002).

The climate in Tunisia is Mediterranean, characterised by hot dry summers and cool moist winters that limit the growing period. Tunisia is divided into four large geographical units: Northern, Eastern, Central and Southern regions. According to Emberger (1960) there are five bioclimatic zones in going from the most arid to the most humid based on rainfall (see Climate Description section). Rainfall is not the only bioclimatic determinant; temperature and especially winter temperature is also important. This is not only governed by altitude but by the degree of continentally: the sea has a buffering effect on areas close to it, while inland stations have relatively hotter summers and colder winters. Sometimes temperatures may rise to 48°C maximum.

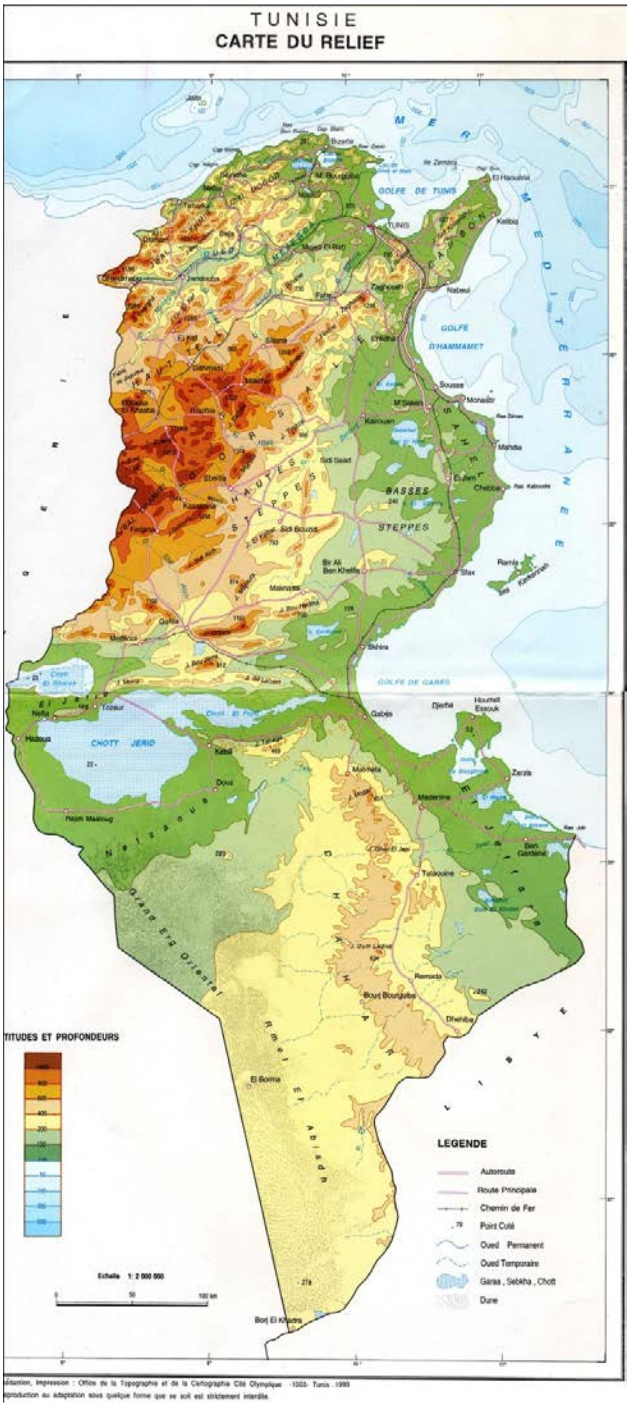


Figure 8: *Map of Tunisia*

Bio-climatically, therefore, the country is also divided into areas of warm, cool and cold winters (Kayouli, 2000).
Variations in rainfall depend with the distance to the Mediterranean Sea and the altitude. The wet season is from November – February, while the dry season (summer) lasts from June – August and is almost completely rainless. However, when there is rainfall, it is highly irregular and intensities may reach 100 mm/h for 5 min. This makes it very difficult to do any predictions on this (Schiettecatte et al., 2002).
Also the winds have a large influence on the difference in climate between winter and summer. In winter, dominant winds come from the east- north east and are humid; in summer they come predominantly from the south east, are hot, dry and, and they can have a drying effect on vegetation. They are also known as the sirocco (brittanica.com, 2011).

The economy with a total GDP of $100.3 billion (CIA world factbook, 2010) thrives mostly on minerals (phosphate) and (crude) oil, as well as on tourism. Agriculture constitutes only 10,6%, while it constitutes 22% of the total workforce (nationsencyclopedia.com, 2011; CIA World Factbook, 2010).

The study site is located in the southern region of Tunisia (Figure 8). "It stretches from the Mediterranean Sea (Gulf of Gabes) to the fringes of the Great Oriental Erg passing through the low plain of Jeffara, the Matmata mountain and the open rangelands on the Dahar plateau. It is drained by two Wadis: Oum Zessar ($367km^2$) and Hallouf Dahr (530 km2)." (WAHARA Report)

SOILS AND TOPOGRAPHY:

Topographically speaking, Tunisia can be divided into four large geographical units (FAO, 2010):

a) North: characterized by mountain chains of Kroumeriee Mogods
b) Dorsale: characterized by hilly relief and plains with fragile soils
c) Center: characterized by its aridity
d) South: Mountainous areas (Matmatas), Coastal plains (Jeffara), Large Depressions (Chotts) and the Desert zone (Erg)

The study site is located in the South region. The next table shows the soil types in each area:

Table 6: *Soil types in the South region per Area*

Area:	Soil type/Land cover
Mountainous Area (Matmatas)	- Agriculture is based on spate irrigation - Limestones and calcic-marly soils (in the mountains) where lithosols develop - Fluvisols (in the major river valleys and in alluvial fans)
Coastal plains (the Jeffara)	- High Jeffara: crusted glacis where the soil is formed in one horizon with light texture (calcic paleorthid). - Low Jeffara: crusted soils (paleorthids, calciorthids, cypsiorthids) but with the appearance of the crystalline basement rocks consisting of gypsum at the surroundings of the "sebkhats" and the large depressions that are formed of salty soils (salorthids).
Large Depressions ("Chotts")	- Souther chott: Sandy soils - Very salty soils (true desert)
Desert zone ("Erg")	- Dunes of sand - Very sparse vegetation

[source: FAO, 2010]

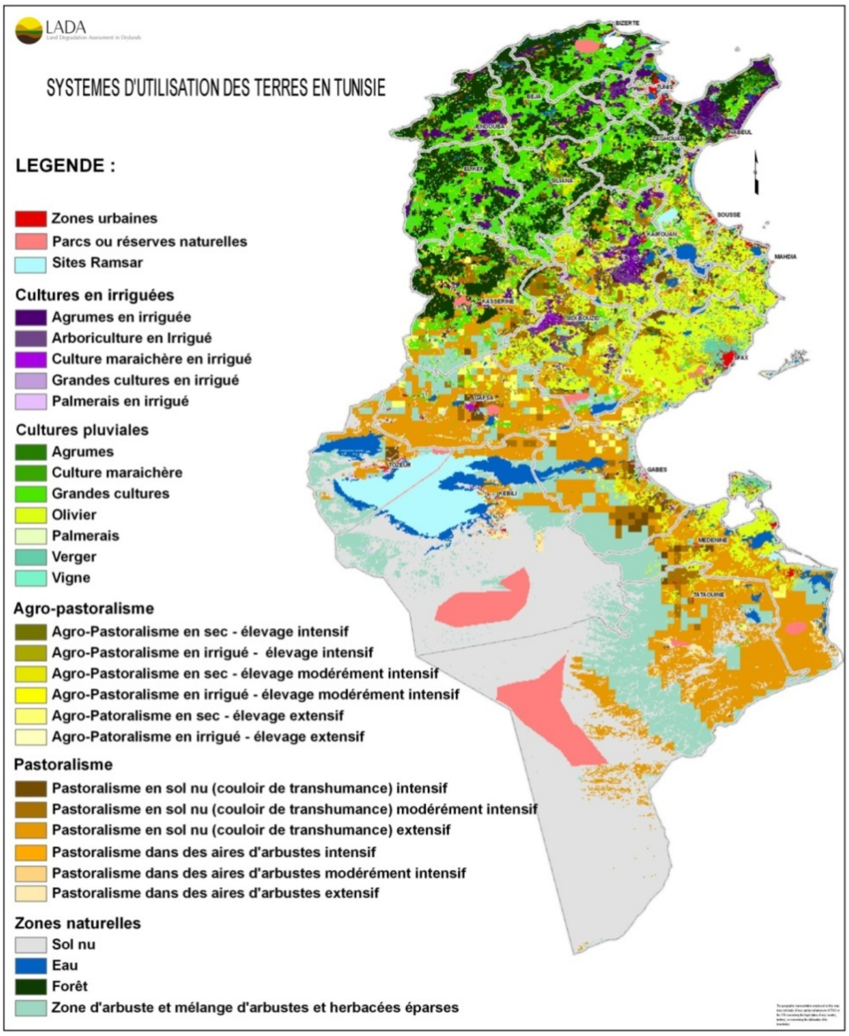


***Figure 9**: Vegetation and dominant land use of Tunisia (LADA, 2011).*

Figure 9 illustrates the land-use in Tunisia. Focusing on the study site area, agro-pastoralism and pastoralism are the dominate land uses. In general, in an area of 125,000 km^2, 76,000 km^2 is considered agricultural land, of which 47.000 km^2 is arable, 28,000 km^2 grazing and forests lands and the remaining 6,000 km^2 is fallow (FAOSTAT/ AQUASTAT, 2007).

As land for crop production is scarce, livestock has an important share of agricultural production: it contributes approximately 40 % of the total agricultural product, but this is clearly inferior to cereals and olive that dominates traditional Tunisian agriculture. However, most of this production is done in the north. In recent years, the government has been encouraging animal production to increase national self-sufficiency in animal products (meat and milk). In total, there are 380,000 farms in Tunisia and 65 % keep livestock, mainly smallholders, with an average agricultural area under 20 ha. who represent 80 % of the livestock statistics for 1998. 65% of the cattle are in the North, 60 % of sheep and goats are in the Centre, and 80 % of camels in the Centre and the South.. Other agricultural products are olive oil, citrus fruit, sugar beets, dates and almonds (CIA World Factbook, 2010).

LAND TENURE:

Since independence from the French in 1956, Tunisia has undergone three major shifts in land tenure policies. First, in 1956, collective system of landholding (habous) was eliminated by the government and replaced with a system of private property land rights. This aimed at eliminating usufructuary rights to land. Second, in 1961, two changes in land tenure systems occurred. First, state farms were created from the acquisition of land that was owned by colonial settlers. Second, these were transformed into cooperative (socialist) system (of surrounding peasant farms). The third major shift occurred in 1970, here cooperatives and state farms were abandoned and replaced with privatization. "Some cooperatives, remained as state property"(Zaibet, 1998). In 2002, it was established that there are four kinds of land tenure systems in Tunisia (i) tribal system ii) state sponsored cooperative systems (state farms) and (iii) private system, and iv) The co-management system (here the "community cedes control of overgrazed pastures to the Forest Services for pasture improvement")(Nefzaoui, 2002)

CLIMATE:

Table 7: *The five bioclimatic zones in Tunisia (Kayouli, 2000)*

Annual rainfall (mm)	Bio-climatical strata
800 - 1200	Humid
600 - 800	Sub-humid
400 - 600	Semi-arid
100 - 400	Arid
20 - 100	Desert (Saharan)

As can be seen from the table below, the area can be classified as arid (based on the five bioclimatic zones described before). During the months of May-Aug there is less rainfall than during Sept-Apr and during this year the area experienced 31.5 days of rain. The mean average temperature is about 19.3°C and the reference evapotranspiration varies with the highest value in July (202mm) and lowest between Nov-Feb (75-60mm).

Table 8: *The meteorological data for the study site:*

Latitude: 33.730° Longitude: 10.000° Elevation: 211m

Month	Prc.	Prc.	Prc.cv	Wet days	Tmp.mean	Tmp.max.	Tmp.min.	GrndFrost	Rel.hum.	Sunshine	Wind(2m)	ETo	ETo
	mm/m	mm/d	%	days	°C	°C	°C	days	%	%	m/s	mm/m	mm/d
Jan	21	0.7	125.0	3.3	11.1	15.6	6.7	5.1	63.3	69.6	2.5	61	2.0
Feb	18	0.7	117.3	3.0	12.6	17.5	7.7	3.5	60.5	70.8	2.5	72	2.6
Mar	24	0.8	109.8	3.9	14.6	19.6	9.6	1.9	61.6	68.1	2.5	102	3.3
Apr	20	0.7	128.6	3.2	17.5	22.4	12.7	0.9	61.8	68.9	2.8	127	4.2
May	9	0.3	148.5	2.4	21.1	26.0	16.2	0.4	62.5	72.5	2.8	160	5.2
Jun	5	0.2	180.7	1.3	24.7	29.5	20.0	0.2	62.7	74.8	2.7	177	5.9
Jul	1	0.0	342.6	0.7	27.1	32.4	21.9	0.1	59.3	84.3	2.4	202	6.5
Aug	2	0.1	295.2	0.8	27.8	32.9	22.7	0.1	61.7	84.3	2.4	192	6.2
Sep	21	0.7	139.4	2.1	25.5	30.3	20.8	0.2	64.2	75.1	2.4	148	4.9
Oct	40	1.3	121.3	3.7	21.3	26.0	16.6	0.4	63.6	73.6	2.2	111	3.6
Nov	23	0.8	119.5	3.8	16.1	20.8	11.4	1.2	62.7	72.4	2.1	75	2.5

Dec	27	0.9	123.2	3.3	12.1	16.6	7.7	4.0	65.2	69.2	2.5	60	1.9
Total	211											1 487	

[source: AQUASTAT, 2011]

AGRO-ECOLOGICAL ZONES:

***Table 9**: The agro-ecological zones (Kayouli, 2000)*

Zone	Annual rainfall (mm)	Agriculture and land use
North	500 <Rain <1000	Natural forest, maquis and grazing areas; possibility of rainfed crops: annual crops and horticulture
Dorsal	400 <Rain <500	Forest, maquis and rangelands but fragile; possibility of cropping but with risky annual crops and tree crops adapted to edaphic and topographic conditions
Centre	200 <Rain <400	Forest and maquis very fragile in favourable edaphic and topographic conditions. Rangelands are fragile. Possibility of cropping but with risky annual crops and tree crops,
South	Rain < 200	Very fragile steppe in favourable edaphic and topographic sites. Rangelands very easily degraded. Rainfed agriculture is locally possible with good management of run-off.

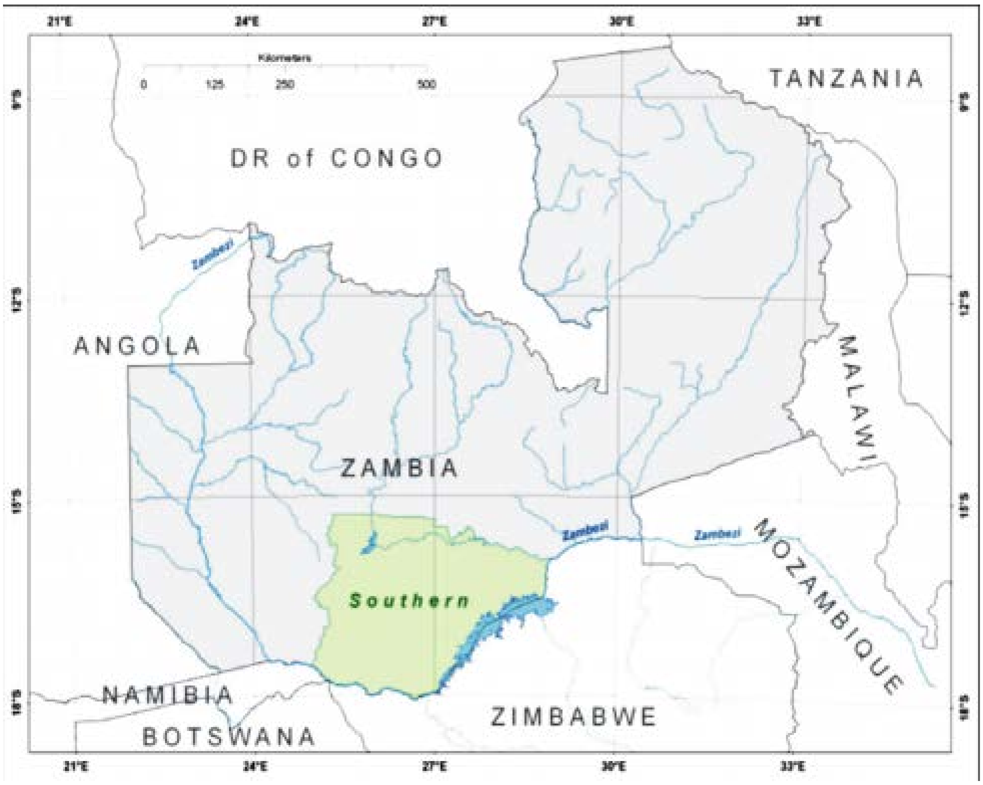
The agro-ecological zones are based on the four large geographical units. The study site is located in the South zone.

Zambia

INTRODUCTION

Zambia is a land locked country measuring 752,629 km^2 in extent and lying between latitudes 8^o and 18^o South and longitudes 22^o to 35^o East. It is boarded by Angola, Namibia, Zimbabwe, Botswana, Tanzania, Mozambique, Malawi and the Democratic Republic of Congo (Figure 10). Most of the country is drained by the Zambezi River basin (forming the expansive Kariba Dam) in the south whilst a small proportion is drained by the Congo River basin in the north.

***Figure 10:** Map of Zambia showing the local study site*



Zambia is a fairly large and sparsely populated country in the Southern Africa region. Currently the population of the country stands at 12.9 million. With an annual population growth of 2.5% it is set to increase to 19.2 million by 2025 (WRI). The population is spread over 73 diverse ethnic tribes with 3 dominant groups. These groups are the Bemba (North) the Tonga (south) and Lozi (west) (CSO, 2009) (WRI). Of the estimated total population about 1 million live in the rural areas of the southern province where 76% of them live below the poverty datum line (CSO, 2000). Ethnicity in this region is dominated by the Tonga (69.8%) and the Nyanja (5.5%). Governance of rural communities is through a democratic modern political setup (rural council) intertwined with an inheritance based traditional governance system. This results in a political party based councilor working in conjunction with a traditionally appointed village head and or headman. These leaders work together and coordinate rural development work following the provisions of the national local governance structures and laws.

Around 70% of the country's population is dependent on agriculture, which is practiced under three main broad categories which are small scale, medium scale and large scale agriculture (IDL group, 2002). The majority of the people however practice small scale agriculture which is usually at subsistence level. These subsistence farmers produce mainly staple crops, maize and legumes for food purposes with occasional surpluses sold on the market. Cotton, wheat, soya beans, tobacco, beans, groundnuts and sugarcane are produced mainly as cash crops (Zambia Land Alliance, 2005). In the study area agriculture contributes more to the $300 GDP per capita per year (Wahara). Other economic activities which are off farm include fishing, honey gathering and selling, charcoal making and casual laboring (Riché, 2007) (ZVAS, 2004).

Its climate is primarily sub-tropical and characterized by extreme seasonal and climatic variations (Chabwela and Mumba, 1998). In the Southern region where the study area Batoka is located, agriculture is the major economic activity supporting livelihoods (WAHARA). With extreme climate variability, a changing climate and a rising population, current water management strategies, including water harvesting technologies within in Batoka and those with potential to be adopted there, have to be reviewed for potential up-scaling to prepare the water dependent population for the future, in a changing world.

SOIL AND TOPOGRAPHY:

Zambia is generally located on a high plateau with an altitude ranging between 900 to 1500 meters above sea level (Mwila et.al, 2008). The plateau slopes gradually from the North East to the South West of the country where the Batoka area is located. On average the altitude of the Batoka area is 1300m above sea level with its topography generally flat to gently undulating, with slopes usually less than 5% (Wahara, 2010). Country wide soils are mainly loamy-sands or sand interspersed with clay Alfisols whilst the study area has Ferric Acrisol and luvisols, reddish-brownish clayey-loamy soils derived from acidic rocks (GRSP, 2007). The soils also have a low pH, are low in organic matter content and are susceptible to degradation also once opened up (GRSP, 2007) (Wahara, 2010).

The vegetation of Zambia is dominated by dry Miombo woodlands which gradually turn into dry evergreen forests when merging with wetlands (Aregheore et.al, 2009). In Batoka, regenerating Miombo woodlands dominate the landscape, whilst open grasslands are evident in wetlands and other riverine ecosystems (Wahara, 2010). Major land use systems include open Miombo woodlands, agricultural cropping and pasture lands.

***Figure 11**: Picture generally showing a typical agricultural field, Miombo woodland and hilly and sloping terrain with regenerating open grasslands.*

Land holding for subsistence farmers in the Batoka area is through customary use rights, accessing land from the government through a customary tenure system by getting the approval of traditional leaders such as chiefs and headman (Kajoba, 2004). Constraints for the communities to achieve full potential to move towards development include the infertile soils unproductive farming methods, erratic unreliable rainfall, poverty and generally a not diversified rural economy which is solely dependent on agriculture (WAHARA, 2010).

CLIMATE:

Zambia has a tropical climate, which is strongly modified by altitude in the country (Aregheore et.al, 2006). The climate is mainly driven by the movement of the inter-tropical convergence zone (ITCZ) (Hachigonta and Reason, 2006). It is characterized by three distinct seasons which are a cool dry season (April-August), a hot dry season (August-November) and a warm to hot wet season, (November-April). In the southern province, the area experiences a hot semi arid Steppe climate with higher temperatures and lesser rainfall corresponding to the Class Bhs according to the Koppen-Geiger classification (GRSP, 2007). Frost occasionally occurs during calm nights in some areas especially in the cool season (Aregheore, 2006). Excessive heat and high humidity are experienced in the Zambezi valley usually in October and in the wet season respectively. Rainfall varies from 500 to 1,400 mm per year with most areas receiving 700 to 1,200 mm. Most of the rain falls in the hot wet season as thunderstorms which are inter spaced with at most of the times dry spells characterized by bright sunshine. The mean annual temperature range is between 18^0C and 20^0C. The highest annual average temperature being 32^0C and the lowest temperature averaging at 4^0C. Usually throughout the year winds are dominated by south easterly winds (Hachingota and Reason, (2006)

Table 10: *The meteorological data for Batoka*

Month	Prc.	Prc.	Prc. cv	Wet days	Tmp. mean	Tmp. max.	Tmp. min.	Grnd Frost	Rel. hum.	Sun shine	Wind (2m)	ETo	ETo
	mm/m	mm/d	%	days	°C	°C	°C	days	%	%	m/s	mm/m	mm/d
Jan	215	6.9	39.4	17.1	23.1	28.1	18.2	0	78.8	44	0.9	119	3.8
Feb	189	6.8	45.6	15	23	28.3	17.8	0	79.1	48.8	0.8	108	3.9
Mar	89	2.9	70.7	10.1	22.7	28.6	16.9	0	75.8	60.6	0.9	122	4
Apr	28	0.9	125.3	1.9	21.4	28.5	14.3	0	69.4	75	1	115	3.8
May	3	0.1	276.6	0	18.6	27	10.2	0.8	62.4	81.6	1	103	3.3
Jun	0	0	488.6	0	16.4	25.2	7.6	3.5	58.9	82.5	1.1	89	3
Jul	0	0	506.9	0	16.2	25.2	7.2	3.9	54.8	83.8	1.3	99	3.2
Aug	0	0	504.2	0	19	27.7	10.3	1	47.1	86.6	1.4	126	4.1
Sep	1	0	254.9	0	23	31.3	14.7	0	41.2	80.3	1.6	157	5.2
Oct	25	0.8	121.5	3.3	24.9	32.3	17.5	0	46.4	72.2	1.6	175	5.6
Nov	88	2.9	57.3	8.4	24.8	31.3	18.4	0	57.3	56.4	1.3	148	4.9
Dec	210	6.8	45.5	15.5	23.4	28.6	18.3	0	74.4	46.2	1.1	127	4.1
Total	848											1 488	

As can be seen from the table, during the months of May-Sept there is little to no rainfall, while Oct-Apr can be characterized with having medium to high rainfall. This year the area experienced 31.5 days of rain. The mean annual temperature is about 19.3°C and the monthly potential evapotranspiration varies with the highest value in Oct (175mm) and lowest between Jun-July (89-99mm).

AGRO-ECOLOGICAL ZONES:

According to the Zambian agro ecological zone classification system, the country is dived into 4 basic classes. Table 2 and Figure 3 below describe these zones in brief (Siacinji-Musiwa, 1999).

Table 11*: Zambia agro-ecological zones*

Zone	Area	Rainfall	Crops
I	Western Southern part (Central, Southern and Eastern Plateau)	800mm Low rainfall	Maize \legumes(bread basket of nation)
II	Stretches from east to west (western, semi-arid plains)	800-1 000mm Medium to high	High agricultural production

IIB	Central Western (Western arid plains)	800mm Low rainfall	Dry areas
III	Northern part (The Northern, Northwestern high rainfall zone)	1 000mm High rainfall	

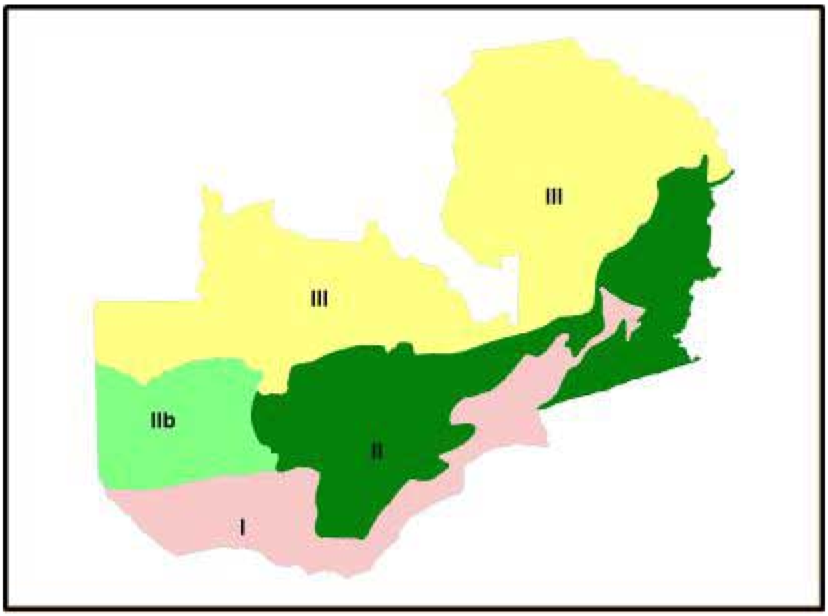


Figure 12: *Agro-ecological Zones of Zambia*

The area of interest can be classified into two agro-ecological zones namely zone I and zone II. Zone 1 used to be termed the breadbasket of the nation but however, it has suffered to extreme climate variability over the last 20 years which have been usually dry with an un evenly distributed rainfall. Zone 2 has had more of a relatively evenly distributed rainfall patterns and has highly fertile soils (de Wit and Jain, 2006).

PROBLEM ANALYSIS & OBJECTIVES

Although water harvesting technologies have been used since time immemorial, issues of their scaling up and adoption in different communities have hindered their spread and hence their effectiveness in reducing hunger and poverty in Africa. Additionally, little knowledge is available on the impacts of specific WHT's categories under different biophysical and socio-economic circumstances. Site specific and or universal indicators of potential impacts of WHT's have not been fully developed to the extent of being used in a wide range of agro-ecological and socio-economic setup.

The main objective of this report is to provide a review on local small scale innovative water harvesting techniques for specific African agro-ecological zones. The ultimate aim is to provide information for probable up-scaling and adoption of these innovations.

With this in mind the report tries to provide answers to the objectives stated above through answering the detailed research questions below:

Research questions:

1. What are the in use small scale water harvesting technologies in the specific agro-ecological zones?

2. What are the potential small scale water harvesting technologies that can be adopted in the specific ago-ecological zones?

3. What are the potential environmental, socio-cultural, economic and technical impacts of selected WHTs categories?

3.1. What are the costs?

3.2 What are the on-site and off-site impacts?

3.3 What are the potential indicators for the impacts and what methods can be used to asses them?

METHODOLOGY

A desk based literature study was conducted to provide adequate insight and information into the study questions. The WUR library was used extensively to provide supporting scientific facts. Guided interviews were done with experts that included Pieter van der Zaag (UNESCO) and William Critchley (Vrije University). Interviews were also conducted with a number of African and Asian students to gather further insights into the study questions. Expert guidance was received from Jan de Graaff (WUR). A first categorization was carried out according to the agro-ecological zones defined by the study sites of the WAHARA project (see "country review" section). Later on, in collaboration with the commissioner, Frank van Steenbergen, a set of 9 categories were drawn according to the technique typology of the measures screened during the literature study and obtained from the interviews. Universal impacts per category where derived and grouped into environmental, socio-cultural, economic and technical impacts based on literature, interviews and the inherent experiences from group members. Indicators for the impacts were developed, and together with suggested impact analysis tools formed a tool box to assess the potential impacts of WHT.

RESULTS & ANALYSIS

At a first glance water harvesting might appear as an extremely broad family, comprising of all those techniques that make use of rainwater, sheet flow and concentrated flow for a fruitful and productive use. If in-situ water conservation methods are considered as part of it, a big share of agricultural practices would fall in the definition and real water harvesting would be only a marginalized subgroup of it. The boundlessness of the term has led the definition to either be clear and straight forward or fussy and misused. For this reason we will consider as water harvesting all the techniques that imply the presence of a catchment area and of a separated cultivation area (described in category n. 3). Nevertheless, we will not confine our research only to WHTs, but we will also include a broad range of different practices that can be adapted to become WHTs or that can be combined with it to harvest the maximum benefits. The terminology and what is considered WHT can also change from place to place. For example in India water harvesting is mainly focused on filling reservoirs and thanks. Even when the final use is agriculture, the water is often stored in reservoirs instead of being directly diverted to the fields (Critchley, 2011). In our case we focussed on what is perceived as runoff agriculture in rain-fed areas, with a particular attention to the importance and conservation of green-water. Furthermore, this chapter tries to give an account of what has been practiced in Africa and what are the main consequences. When possible monetary costs are be provided.

Every category is first described highlighting the main differences between WHTs and afterwards two tables characterize the main effects and costs. The first table briefly explains the costs of each category whilst the second table portrays the main environmental, economic, socio-cultural and technical impacts. The cost figures are unprocessed data collected from a wide source of literature and particular attention has to be paid to make use of it. In fact monetary costs have little meaning when not coupled with real life figures describing the economic situation of a given country. For instance the wages, the currency rates and material costs might be extremely different even for neighboring countries.

The second table after each category of the following chapter gives a set of indicators that can be used alone to evaluate specific aspects of the WHTs or within the framework of one of the five tools that are presented in the session “proposed toolbox for impact assessment”.

The usage of indicators in impact assessment

For the monitoring and evaluation of WHT projects, it is necessary to predict and assess its impacts in order to say something about whether a certain measure was successful or not. However, many projects in developing countries have limited themselves to focus on financial and physical assessment, which includes among others the time spent to implement the measure and the total area covered (implementation rate) (De Graaff & Kessler, 2009).Emphasis must thus be put more on the output of the products that relate to the objectives of such projects. In the case of water harvesting, the objectives will be in the order of increasing the available surface/ groundwater water, increasing crop yields and improving soil fertility. Although soil moisture and water tables are relatively easily measured, socio-cultural impacts (which may also be included in some of these projects) are a lot more difficult to measure. To assess what will be the impact and the effects of a certain technique, the development of a set of indicators can assist in tracking these impacts. To develop these indicators, it is important to get a clear view of the effects of a certain measure and use these effects as the working hypothesis. Usually this should be done by all stakeholders involved, however in this project we used existing literature to assess the impacts of techniques in various locations (Herweg, 2007).
Assessment of a project however, can become a lengthy and costly process and often both are not available. It is therefore, important that a set of indicators is made SMART (simple, measurable, acceptable, realistic and time-bound). Herweg (2007).has made SMART more specific for SWC indicators. According to him they should be:

- Specific (clear relation between indicator and changes to be monitored);
- Unambiguously measured and interpreted;
- Independent (not subjective to different interpretations)
- Sensitive to changes;
- Easy to collect.

For the main categories indicators can be selected and then used for measuring:

***Table 12**: Categories of the possible impact and relative indicators*

Impacts	Indicator
Environmental	- Water storage capacity (m^3) - Occurrence of pests and weeds - Run off rate (m^3/s) at outflow point. - Main crops production - Nutrient content, organic matter content - Water infiltration rate (%) - Evaporation rate (%) - Biomass production (kg/ha) - Soil moisture (%)
Socio-cultural	- Willingness to apply the technique - Knowledge about the technique - Number of farmer adapting new technologies - Division of work by gender - Conflict management
Economic	- Crop yield (kg/ha) - Fertilizer cost ($/bag) - Famers' income ($/day) - Area (ha) - Variety of crops - Cost ($)
Technical	- Requirement of materials, tools, labour and design of techniques - Time to train people to use the technique

N.B.: The use of indicators can be a tool on itself, but also used as an input for other tools, which will be discussed below.

1. In-situ moisture conservation and retention - Soil moisture

One of the most widely known and applied techniques to preserve soil moisture is the adoption of organic material within the farming system. Compost and manure are often applied for their capacity of influencing the chemical and physical properties of the soil and increasing the water retention capacity. When potential evaporation is particularly high a mulch of plant materials such as crops remains can be spread on the fields to decrease the overall evaporation, decrease runoff speed and favor infiltration.

Composting is the process used to produce high quality organic decomposed material that has high water holding capacity and that favors water retention, it improves infiltration and it releases nutrients slowly into the rhizosphere. Compost is usually produced with local sources such as crop residues, household refuses and animal manure. This process is faster than natural decomposition because all the conditions for the decomposing microbes are optimized. The most simple way to produce compost is often the use of simple heaps where the material is accumulated and natural decomposition processes are favored by maintaining an optimal humidity and temperature and by occasionally turning over the decomposing matter (Hudson, 1987). The use of compost is of particular importance in poor soils with a low percentage of clay where water is often lost through deep percolation (Ouédraogo et al., 2001). On top of this, through composting, the need of expensive fertilizers is decreased and by selling eventual surplus it might even generate an extra-income for the household (Sreedevi..., 2009).

In Burkina Faso heaps are widely used to produce compost to be later used in association with planting pits. In every pit, the material is incorporated and mixed together with a handful of loose soil (WOCAT database). Often the combination favors the activity of termites that by tunneling increase the aeration, the structure and the water holding capacity (Stroosnijder, 2003).

***Figure 13**: Fosse fumiere used for making compost in Burkina Faso*

With mulching the farmer can achieve: reduced evaporation, increased infiltration, effective weeds and runoff control. A wide range of different materials can be used for mulching. The most common, low-cost materials are often agricultural residues, cut weeds and straws (Duveskog, 2001). Due to the scarcity of such components the area covered by mulching is often localized around the plants and does not cover the entire extent of the field (Mati, 2006). In fact, only between 30% and 70% percent of the cropping area is covered (Duveskog, 2001). When mulch is applied the non-productive use of green-water is diminished causing an augmented availability for plant up-take and therefore an improved water productivity (Karlberg et al., 2009). Other materials can also be used such as polyethylene sheets and trimmed rubber from old tires, but these require extra expenditures for the farmer. In other cases also rocks can be used as mulch in the case of the arenados used in the Canary Islands (Tejedor et al., 2002). Mulching is not a very common practice in Kenya (Mbeere district), but when used is mainly applied on high value crops and the materials used are mainly dry grass and crop residues (Onduru et al., 2002).On the other hand, in the Sahel mulching is becoming a common practice (Stroosnijder, 2003). In South Africa, mulching combined with strip cropping showed remarkable improvements in the farming system.

Costs

Techniques	Countries	Cost	Remark	Reference
Manure + termites	Burkina Faso			Stroossnijder. (2003)
Fosse fumiere (compost pit)	Burkina Faso			Critchley et.al. (1991)
Composting associated with planting pits	Burkina Faso	$8/ha	Cost including digging process, fertilisation of manure and composting	UNEP-Africa. (1998)
Natural arenados	Canary Island			Tejedor et.al. (2002)
Artificial arenados	Canary Island			Tejedor et.al. (2002)
Green manure	Nepal, Bolivia			Evans et.al. (2001); Wood, C.D. and Johnson, J. (1993)

Mulch tillage	Zimbabwe	$40/ha (minimum tillage), $120/ha (zero tillage)	Costs including labour and operation cost	UNEP-Africa. (1998)

Impact

Impacts	Advantages	Disadvantages	Indicators
Environmental	- Increases water storage capacity - Reduces runoff - Increases soil fertility (mulch tillage, compost pit) - Improves infiltration - Reduces evaporation - Increases vegetation cover - Retains soil moisture	- Competes with the main crops (mulch tillage) - Potential to become weeds or pests (mulch tillage)	- Water storage capacity (m3) - Occurrence of pests and weed - Run off rate (m3/s) at outflow point. - Main crops production - Nutrient content, organic matter content - Water infiltration rate (%) - Evaporation rate (%) - Biomass production (kg/ha) - Soil moisture (%)
Socio – cultural	- Culturally acceptable (compost pits, mulch tillage) - Improves knowledge for local people - Easily adopted - Emergence of new social roles (mulch tillage)	- The competition between crop use	- Willingness to apply the technique - Knowledge about the technique - Number of farmer adapting new technologies - Division work by gender
Economic	- Increase crop yield (mulch tillage) - Reduce fertilizer cost - Increase income - Saves the land - Supports wider range of crops - Low cost	- Additional cost for labour, construction and maintenance	- Crop yield (kg/ha) - Fertilizer cost ($) - Famers income ($) - Area (ha) - Variety of crops - Cost ($)
Technical	- Simple to construct - Easy to operate	- Need extra effort for maintenance (compost pit) - Need to keep animal away to avoid plant damage	- Requirement of material, tool, labour and design of technique - Time to train people to use the technique

2. In-situ moisture conservation - Agronomic measures

Good land husbandry cannot avoid a holistic approach that integrates sound water harvesting techniques with different agronomic practices. Such techniques are often part of the common knowledge, but when used effectively in a way that fits the local conditions their potential becomes evident and fruitful. Many agronomic measures refer to the right tillage method, the right design of the farming system and the management of the crops. This approach together with WHTs can lead to a better water productivity.

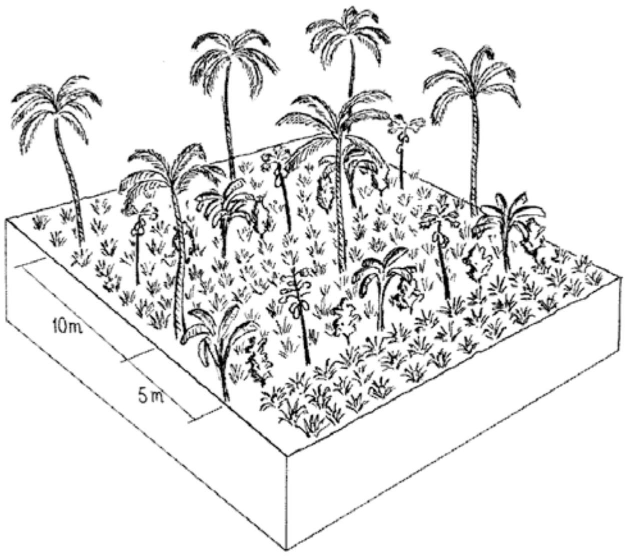
Many different tillage methods exist and range from highly mechanized systems to the use of animal traction or the use of simple hand-tools. This wide range of techniques covers all the situations present in Africa, even-though most of the tillage is still carried out without use of tractors. With an ever growing population and consequent demographic pressure on the land, solutions that are contingent to the region, to the culture and to the resources available have to be developed in order to cover the food consumption needs (FAO, 1993). Conventional tillage leaves less than 15% of crop residues on the soil surface and often comprises multiple passages of the tractors to refine the seedbed. On the long run this practice might have negative effects like increased erosion and compaction, hindered percolation together with high energy and time requirements. In particular where the land is sloping and there is a higher erosion risk particular strategies might be used to counteract the issue (El Titi, 2003). On the other hand, conservation tillage refers to all those techniques that leave at least 30% of the soil surface covered with residues. Conservation tillage includes techniques such as zero-tillage, ridge-tillage, mulch tillage and minimum tillage (Derpsch et al., 2003). When zero tillage is used the fields are left untouched from the harvest moment until the seeding of the new crops except the occasional nutrients injection. The sowing is usually carried out with the help of coulters, disk openers, and tine openers (El Titi, 2003). Often fertilization is carried out together with the sowing of the new crop using the same machine. In Africa, zero tillage has been documented in Tanzania and Nigeria. In the USA zero tillage is successfully used in the area where rain-fed agriculture is practiced. A major disadvantage of zero-tillage is that in order to control weeds a massive use of herbicide is often needed

(FAO, 1993).

***Figure 14**: Corn cultivation in a modern no-till farming system (source: www.no-till.org)*

Reduced tillage on the other hand entails the tillage of just a portion of the field (<30%) (El Titi, 2003).It is widely used in Southern and Eastern Africa (Kenya, Malawi, Zimbabwe) (Technology, 1998) and it can be either mechanized or implemented with hand-tools as the hand hoe, an instrument used to create a small planting pit (Duveskog, 2001). In general, when the tillage is carried out along the contour lines the farming system is referred to as contour farming. All the agricultural operations are carried out following the contours and not going along the steepest gradient as it is often done (Duveskog, 2001).
Some other tillage operation can optimize the use of green water. In some cases a shallow rupture of the surface capillarity with a shallow scratching can decrease the loss of water through evaporation (Jalota and Prihar, 1998). In 1998, a special kind of plough was developed to create micro-catchments for reforestation in Niger. The technology showed excellent rates of tree establishment (Prinz and Malik, 2005, #18630). The Vallerani plough has been used in the Sahel area and in the Northern African eco-region (IWMI). The practice of ripping is used to loosen the soil without inversion. A narrow tined point is used for the operation and requires lower draft power and inputs compared to ploughing (Starkey et al., 1994, #20283).

By introducing innovations in the farming system better use of green water is made possible. Among the possible variations Multi-storey cropping entails the cultivation of different plants species that differ in height and growth characteristics in order to optimize the use of soil and moisture without creating competition (Liniger and Critchley, 2007). Furthermore, Strips along the contours can be left uncultivated with an evergreen leafage of natural plants with the function of slowing down runoff and increasing infiltration (Quinton and Rodriguez, 1999; Liniger and Critchley, 2007). Agroforestry, with techniques such as Alley-cropping provides an alternative farming system in which the annual crop is planted simultaneously with hedgerows of perennial trees. The trees give an alternative source of income and the pruning and leafage can be used as green mulch. Furthermore, the permanent rows built along the contour decrease runoff



and favor infiltration (Kang et al., 1994).
***Figure 15**: Example of alley cropping and multi-storey cropping (from FAO/WOCAT)*

The application of chemical products on the field might favor infiltration or runoff creating the perfect conditions for an eventual WHT use. Polyacrylamide (PAM) is an innocuous synthetic polymer that improves the cohesion and the infiltration properties of the soil. It is already widely used in the USA and is spreading worldwide. Even-though, PAM has been proved innocuous a raising interest is gained by bio-polymers such as starch co-polymers (Sojka et al., 2003).
Other different means of water augmentation exist. Fog harvesting is worth mentioning. In the more temperate west-coast of South Africa fog-water harvesting has been tried to provide water to communities that often suffer from water shortages. The system has already been successfully used in South America (Olivier, 2002).

Figure 16: *Fog-harvesting structures in South Africa (source: www.ngonewsafrica.org)*

Often farmers can also make use of the different plant characteristics to cope with different situations. Improved seeds can produce plants that are better adapted to the local conditions and can lead to the initiation of local seed-banks for stocking and maintaining cultivars locally (Sreedevi..., 2009). Concerning the tree species, the development of new, better performing cultivars could lead to an increased yield and adaptation to local conditions. Vegetative propagation techniques such as grafting have the potential to improve the present plants (Akinnifesi et al., 2006).When grafting, a robust and usually wild rootstock is combined with the aerial part of another cultivar of the same spp., but with more performing characteristics. The techniques have been used on tea plants in Malawi, India and Kenya to improve their resistance to drought (Tuwei et al., 2008).

Costs

Techniques	Countries	Cost	Remark	Reference
Porous Clay Pots and Pipes for Small-scale Irrigation	Chiredzi, Zimbabwe	$40/ha (the cost of labour)		UNEP-Africa. (1998)
Live barriers	Cochabamba, Bolivia			Quinton, J. and Rodriguez, F(1999)
Cover crop legumes	Cochabamba, Bolivia			Barber, R.G and Navarro, F. (1994)
Zero or Chemical Tillage	Zimbabwe	$120/ha	the cost of chemicals and labour	UNEP-Africa. (1998)
Reduced or Minimum Tillage		$40/ha	the labour and operation cost	UNEP-Africa. (1998)
Drought resistant seeds				ICARDA-issue 26. (2009)
Ground breaking for range rehabilitation	Kenya(Baringo)			Mburu, D.M. (2008)
Contour farming	Tanzania			UNEP-Africa. (1998)

Vallerani plough	Niger	€30-100/ha	The cost is according to the size of land and the distance between the plough lines	Vallerani system. (2007)
Nature vegetative strips, vetiver grasslines	Philippines, South Africa			Liniger, H. and Critchley, W. (2007).
Pot and Porous Capsule Irrigation	Mexico, Brazil Bolivia and Panama	$1300/ha (an orchard) and $1800/ha (a vegetable garden)		UNEP-Latin America. (1998)
Multi-storey cropping	Philippines	$1390/ha (establishment) and $490/ha (maintenance)	those costs include labour, equipment and agricultural activities	Liniger, H. and Critchley, W. (2007).
Fog Harvesting	Peru and Chile, Ecuador, Mexico and some Africa countries (see map). Also in China	$90 (Antofagasta, Chile) and $378 for 48 m2 fog collector in northern Chile	$378 for 48 m2 fog collector includes $225 in materials, $63 in labour and $39 in incidentals)	UNEP-Latin America. (1998)
Grafting shoots and roots	Kenya			Critchley, W. 1999
Water-borne manuring system	Uganda	$2288 (establishment) and $76 (maintenance)	those costs include labour, tools, seeds, ferliliser, etc	WOCAT database. (2007)
Sowing andropogon grass alongside bunds to form a vegetative barrier	Burkina Faso			Critchley, W. (1991).
Korbe	Ethiopia	$289 (establishment) and $29 (maintenance)	those costs include labour, tools, seeds, stone, manure, etc	WOCAT database. (2007)
Trashlines	Ethiopia			WOCAT database. (2007)
Improved trash lines	Uganda	$30 (maintenance)	it includes labour and tools	Liniger, H. and Critchley, W. (2007).
Alley cropping (Culture en couloir)	Togo (West Africa)	$156.7 (establishment) and $39.78 (maintenance)		WOCAT database. (2007)
Shallow ploughing	Egypt			ICARDA-issue 8. (2009)
Earthing-up Groundnuts	Tanzania			Mutunga, k. and Critchley, W. (2001)
Biopolymers	USA	$12-36/kg		Sojka R.E et al. 2003
Polymers to enhance infiltration in the	USA	$4-12US/kg	Applying 1-2 kg/ha-1per irrigation	Nishihara A. and Shock C. 2001

cropping area	Vietnam	40cent /kg		The Institute of Nuclear research in Dalat, Vietnam. 2005

Impact

Impacts	Advantages	Disadvantages	Indicators
Environmental	- Reduces soil erosion - Increases soil fertility (cover crops legumes) - Retains soil moisture - Environmentally friendly (fog harvesting) - Provides habitat for biodiversity mainly animal species (nature vegetative strips, multi-storey cropping) - Increases vegetation cover - Reduces evaporation - Increases infiltration	- Decreases environmental quality by pesticide use (chemical tillage) - Potential to become weeds or pests (cover crop legumes)	- Soil erosion - Nutrient content, organic matter content - Environmental quality (soil quality, water quality, air quality). - Biodiversity - Biomass production (kg/ha) - Evaporation rate (%) - Water infiltration rate (%) - Occurrence of pests and weeds - Decrease in main crops production - Soil moisture (%)
Socio – cultural	- Increases food supply - Culturally acceptable (contour farming, tillage) - Improves knowledge for local people - Improves to the aesthetic value of the farm (nature vegetative strips) - Emergence of new social roles (tillage)	- The competition between crop use - Unpopular adopted (fog harvesting)	- Food supply (kcal/day) - Willingness to apply the technique - Knowledge about the technique - Number of farmer adapting new technologies - Division work by gender
Economic	- Increases income - Increases crop yield (legumes) - Can be used as firewood (trees planted) - Reduces fertilizer cost - Increases fodder production (vetiver grassline, sowing andropogon grass) - Low cost (fog harvesting)	- Additional cost for labour, construction and maintenance (pot porous capsule, multi-storey cropping, etc)	- Crop yield (kg/ha) - Fuel cost($) - Famers income ($) - Fertilizer cost ($) - Cost ($)

Technical	- Simple to construct (fog harvesting)	- Depend on climatic condition (fog harvesting) - Special skills for design and maintenance - Need to keep animal away to avoid plant damage	- Requirement of material, tools, labour and design of technique - Climate - Time to train people to use the technique

Impact for polymer treatment

Impact	Advantages	Disadvantages	Indicator
Environment	- Increases infiltration - Reduces soil erosion - Increases fertilizer effect by keeping nutrient in polymer network so they are not washed out. - Increases the soil moisture - Non-toxic for soil (Anionic PAMs) - Reduces run off - Easily metabolized by microorganisms in soil - Not absorbed by plant tissues - Non –toxic to the ground and can be decomposed after 3 year	- Decreases environmental quality (cationic and neutral PAMs can harm sensitive environment)	- Water infiltration rates (20-60%) - Reduction soil erosion (90-95%) - Nutrient content - Soil moisture (%) - Soil, water and air qualities - Decomposition rates (year)
Social	- Decreases labour work for irrigation. - Easily adopted. -Does not require collective action - increases food supply and nutrition - Increases knowledge to the locals		- Number of labour - Willingness to apply the technique - Food supply (kcal/day) - Knowledge about the technique - Number of farmers adapting new technologies
Economic	- Increases crop yield - Low cost technique - No equipment cost - 10 times cheaper than the PAM in other countries.	- Increases farmers' costs to maintain	- Crop yield (kg/ha) - Cost ($) - Technique cost ($)

Technical	- Highly effective for erosion control, runoff reduction and water quality protection - No topography required	- Need to put in the soil at right time (before last rain of rain season) to absorb the water. - Need external material (PAMs)	- Reduction of soil erosion - Water quality - Slopes (%)

3. Concentrating runoff

In regions where rainfall is scarce and/or unpredictable the natural phenomenon of runoff can be used to concentrate and convey extra water for a fruitful use. Instead of being lost through evaporation and transpiration, precipitation by other plants is diverted into a farming area where humidity is stored into the soil profile.

Around the world many techniques are being used to harness the agricultural potential of lands where otherwise water scarcity and variability would hinder a decent agricultural production. The techniques that are often referred to as Water Harvesting Techniques (WHTs) share common features. In order to concentrate the precipitations a sloping surface called catchment area (C) is needed. The C is often a surface with a low infiltration rate such as compacted soil, crusted soil, heavy clays or rocky slopes. The collected water is therefore convoyed directly to the Cultivation Area (CA) where it is directly used by the plants or is stored in the soil as green water for plant uptake in the drier season (Oweis and Hachum, 2009). The extra water gives the plants the means to positively compensate for the water deficit that otherwise they would face (Duveskog, 2001). Different classifications of this wide family of techniques exist and often a boundary is put between macro-catchment and micro-catchment techniques (Critchley et al., 1991).

Micro-catchment :
These WHTs include techniques that rely on a catchment area that discharges directly in the immediately adjacent cropping area. Usually the catchment is relatively small and can be managed by the farmer within his property (Oweis and Hachum, 2009). Within this category we can find many WHTs that are used throughout Africa and are often low-input requiring. In Western Africa pitting is a common practice and it is used to create a micro-environment into small pits were single plants (e.g. millet and sorghum) are grown (Critchley and Reij, 1989; Critchley, 1991). The pits are often implemented on gentle slopes (Duveskog, 2001) together with small bunds built with the dug earth on the lower side of the pit. (Prinz and Malik, 2005) Many variations of this technique can be found in Eastern and Western Africa. The most notorious is probably the Zai pit that originated in Burkina Faso where it is often associated with stone contour bunds and the use of compost. Other known variations are the Kitui pitting and Katumani pitting in Eastern Africa (Prinz and Malik, 2005). Another common WHT is the construction of micro-basins to capture runoff water from up-hill. Semicircular bunds, v-shaped bunds (Reijntjes, 1986), and diamond shaped micro-basins (Prinz and Malik, 2005) are among the most common in Africa. Semicircular bunds are used in many districts of Kenya for pasture improvement where their area can be as big as 300 square meters. In Mali the same WHT is in use for crop production and has a smaller area (<15 square meters) and spacing (Critchley and Reij, 1989). Though similar in shape and functioning eyebrows are used on steep slopes to grow fruit trees (FAO, 2003). In Turkey eyebrows are often associated with olive trees cultivation on sloping fields (Critchley, 2011). In Tunisia the traditional system of meskat is used to grow trees (olive, figs, almond). It is formed by a closed catchment area that through a spillway delivers water to the cropping area that is half the size (C:CA is 2:1). A similar system called Khuskhaba is used in Baluchistan (Oweis, 2004).
Other examples from around the world can be listed. Roaded catchments are successfully used in Australia and consist of strips of land that can be used as a road for the machine and simultaneously they provide water to the cultivation zone (Prinz and Malik, 2005). W-shaped contour micro-catchments are used in Brazil (Reijntjes, 1986)
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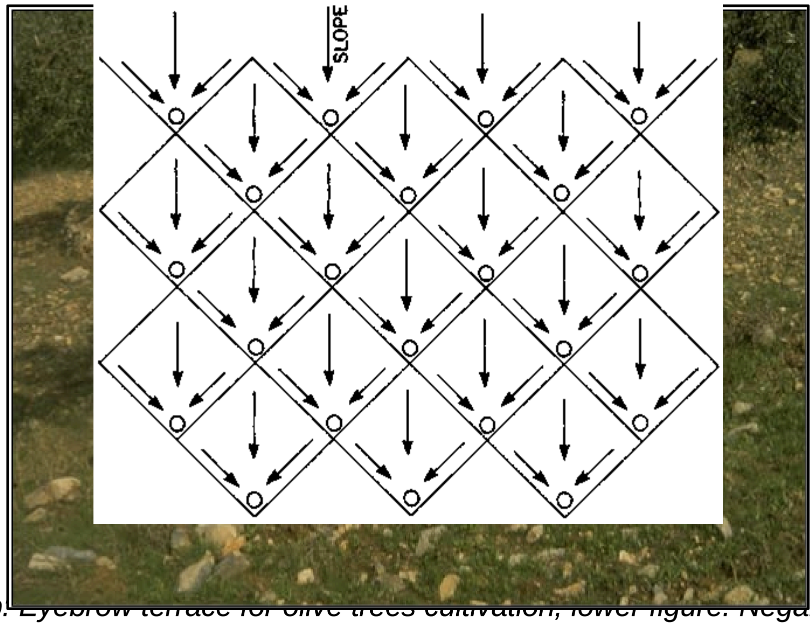


Figure 17: *On top: Eyebrow terrace for olive trees cultivation, lower figure: Negarim micro-catchments*

Macro-catchment:
Often referred as external catchment or long slope WHTs this category often implies a bigger C:CA ratio .Trapezoidal bunds for instance are used to cultivate annual crops in an artificially enclosed farming area that without the runoff water from the catchment area would not be possible. A cultivation area of 0.5-0.8 ha is common and is surrounded by bunds on three sides that gives it the trapezoidal shape. Often the catchment area is external and is often oversized to address drier season. A ratio of 20:1 between C and CA is common in the Turkana district of Kenya (Critchley and Reij, 1989).
Jessours in Tunisia are a technique used in small seasonal streams (Wadis) that run down slope on very arid hill sides. A riser called a tabia traps water and sediments eventually forming terraces (jessours) with soils of up to 2m in depth (Amani 1984.). A really broad catchment area is concentrating water to the CA thanks to a wall that is built across the wadi and is provided with a spillway for excess water (Oweis, 2004)This forces sediments to collect in the jessours and water to collect and to infiltrate to recharge underground systems. Crops including cereals and legumes and trees such as olives, dates and figs are grown in the sediment rich jessours (Noumi, Abdallah et al. 2011) (Prinz and Malik 2002). Teras in Sudan is another form of external catchment, long slope technique applied on gentle slopes (ca. 0.5%) and usually has an area of approximately 3 hectares. It is basically made by bunds on three sides that gives it an open rectangular shape. Furthermore, the plot is divided into sub-sections by smaller arms perpendicular to the lower bund (Critchley and Reij, 1989).

Costs

Techniques	Countries	Cost	Remark	Reference
Infiltration pits	Sahel, Western and Eastern Africa			Mutekwa & Kusangaya (2006), Motsi et al. (2004), Nyagumbo et al. (2008) Paceproject.net – Action sheet 45 - Rainwaterharvesting,

Negarims	various, mainly Arabic, Israël	±500 m3/ha (+/- 300) earthwork size catchment depending; 1 person-day can build 2 units	for slopes <5%, otherwise more	Critchley & Siegert (1991), Paceproject.net – Action sheet 45 - Rainwaterharvesting,
Semi circular bunds	francophone Africa: Niger, Burkina Faso etc.	±150 m3/ha (+/- 50) earthwork size catchment depending		Critchley & Siegert (1991)
Kitui pitting	Kenya			Mati (2005), WOCAT DB KEN13
Trapezoidal bunds	worldwide	construction: ±500 m3/ha (+/- 150) earthwork slope depending		Critchley & Siegert (1991), Hatibu & Mahoo (1999), Mati (2005)
Tassa	Niger	construction: 245USD/ha total including stone lines; 35USD/ha/yr = maintenance		WOCAT database, Liniger & Critchley (2007),
Katumani pitting	Kenya	construction: 100-150USD/ha		UNEP (1998) – SATFAAf, Mati (2005)
Chololo pitting	Tanzania	construction: labour input = 30-40 days/ha; maintenance = 15-20 days/ha		Mutunga & Critchley (2001), Reij (1990),
Zay	Mali, Burkina Faso	construction: 30-70 days/ha; 8 USD/ ha		UNEP (1998) – SATFAAf, Mutunga & Critchley (2001)
Demi-lunes or semi-circular hoops	Niger	construction: 150USD/ha or 10 person days/ha		UNEP (1998) - SATFAAf
Trenches for trees	Niger	construction: 544.880 CFA/ha = 1758 USD/ha (1988)		Critchley et. Al (1992)
Roaded catchment	Australia	construction: 500 AUS$ /acre	1980 figures	Richardson et al. (2004), Stanton (2005)
	USA	construction: 300 USD/acre	1974 figures	Richardson et al. (2004)
Road runoff harvesting	Kenya	construction: 100 days/ha; maintenance: 10 days/ha		Mutunga & Critchley (2001)
Gavias	Canary Islands			Jiménez et al. (2002), Díaz (2005)
Khuskabas/ sailabas	Pakistan			Hudson (1987)
Khadins	Pakistan			Hudson (1987)
Zai with compost	Kenya			WOCAT DB
Contour bunds	Burkina Faso			Reij (1990)

Jessours	Tunisia	TD 642 (2005)		Fleskens et al., 2005

Impact

Impacts	Advantage	Disadvantage	Indicators
Environment	- reduces soil erosion onsite (tassa, Kitui) - useful for rangeland rehabilitation on slopes (Kitui pitting, semi-circular bunds, negarim) - improved soil porosity and permeability (zai, tassa) - leaching of salts (khadins, kuskabas, sailabas, gavias) - Ground water recharge (khadins, kuskabas, sailabas) - increases soil fertility (gavias) - retains soil moisture (tassa, Kitui, infiltration pits, gavias)	- sensitive to waterlogging (infiltration pits, zay, tassa, contour bunds) - only suitable for deep soils (infiltration pits)	- Soil erosion - Nutrient content, organic matter content - Soil quality, - Biodiversity - Evaporation rate (%) - Ground water capacity (m) - Soil moisture (%)

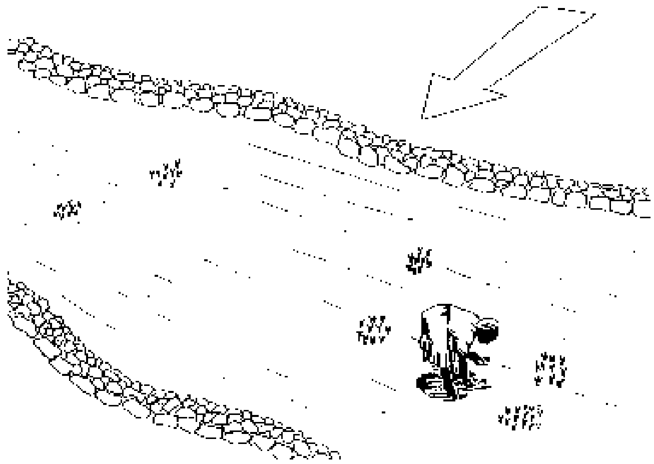
Social	- Increases food supply - easily adopted in Sub Saharan Africa (SSA) (infiltration pits) - locally adapted to Kenya (Katumani pits, Kitui pits) - indigenous origin in East Africa (trapezoidal bunds) - useful for growing cereal crops (sorghum, millet) (trapezoidal bunds) - no extra farming skills required - easily adopted in Niger (tassa) - suitable for remote areas (khadins, kuskabas, sailabas) - easily adopted (zai with compost) - Improves knowledge for local people - does not induce conflicts with socio-cultural agriculture practices (zai, tassa)	- requires organisation, cannot be done by a single farmer (trapezoidal bunds) - land use rights conflicts of rehabilitated (communal) land (Tassa) - conflicts between pastoralists and famers: pasture land --> cultivated - no cattle allowed on plots during growing season(katumani) - promoted but not always adopted in Niger and Kenya - not suitable for densely populated areas (khadins, kuskabas, sailabas, gavias, roaded catchment)	- Food supply (kcal/day) - Willingness to apply the technique - Knowledge about the technique - Number of farmer adapting new technologies. - Conflict over land use - Active participation

Economic	- Supports wider range of crops - (infiltration pits, trapezoidal bunds) - low cost technology (infiltration pits, Caag, zai, chololo, tassa) - increases crop yields (negarims, zay, tassa, stone bunds, zai with stone bunds) - low additional manure required (infiltration pits) - improved fodder production (katumani pitting, infiltration pits, kitui pits) - improved grazing capacity (katumani pitting, infiltration pits, kitui pits, demi-lunes) - maintenance is minimal (Kitui pitting) - low min. CCA ratio 1:3 (negarim)	- labour intensive, also for maintenance - rarely used for crop production (demi-lunes) - capital intensive (roaded catchment)	- Crop yield (kg/ha) - Fuel cost($) - Variety of crops - Famers income ($) - Fertilizer cost ($) - Cost ($) - Working hours
Technical	- easy to construct (negarim, chololo, tassa, zai) - neat and precise (negarim) - regular topography not required if kept large (20m ø) (semi circular bunds) - even useful with very low rainfall (P>=150 mm) - more space available for manure and runoff retention (katumani pits) - can be built with slopes >0.5% (Caag) - easy to operate (tassa) - excess water can be shared with other bunds/ pits (semi-circular & trapezoidal bunds; Kitui)	- not suitable for mechanised farming (negarim, zai, chololo, tassa, demi-lunes, gavias) - trampling hazard: pits and bunds may be damaged (Kitui pits, demi lunes) - not useful for small rainfall events - needs significant clay content (trapezoidal bunds) - vulnerable to breakages after high storm runoff - precise measurements necessary (contour bunds) - even topography needed for collection plain (kuskaba, khadins, sailabas)	- Requirement of material, tool, labour and design of technique - Climate - Time to train people to use the technique - Water capacity (m3)

4. In-field water retention - Contour bunds

When farming on a sloping terrain a great deal of runoff is often generated discharging most of the water outside the field and causing erosive features like rills and gullies. In order to slow down erosion and build up the green water pool of the soil, continuous ridges or bunds can be laid along the contour lines of the slope.

Bunds and ridges are among the most common and simple techniques used to boost infiltration and inhibit erosion. Their use is spread throughout Africa and the construction materials often change according to the local resource availability. The most common materials are stones and dug soil, but sometimes a variation of it is constructed with crop remains. In Burkina Faso, where the land usually has a gentle, continuous and long slope, stone lines are laid along the fields with a spacing of 15-30 meters in between lines. They do not stop the runoff totally, but they slow it down and spread it evenly favoring the cultivation in the often



associated Zai pits (Critchley and Reij, 1989).

***Figure 18** Stone lines in Burkina Faso (Critchley, 1991a)*

In Ethiopia stone bunds have been built to form macro-catchments for cultivation on slopes of 2-3% (Hailu and Merga, 2002). Often earth bunds with a spacing of 5-10 m and with upward ties are used for cultivation of trees and crops in the inter-rows spacing. The ties are meant to create consequent micro-catchments along the line and can be built manually or with special machines.

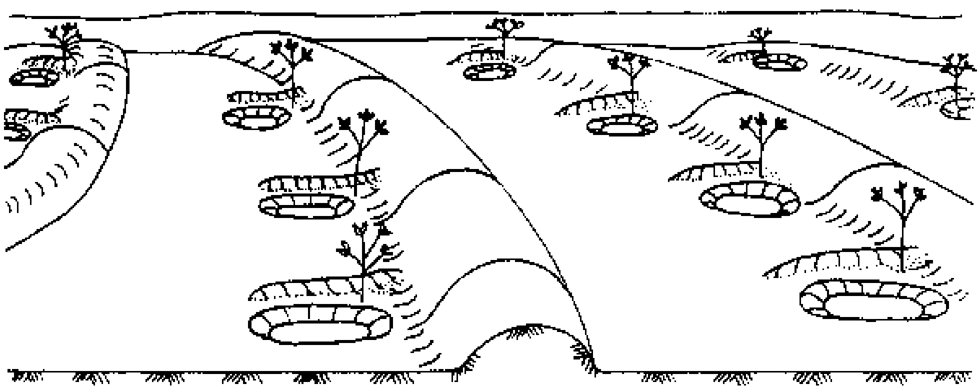


Figure 19: Earth bunds with ties (Critchley, 1991a)

On the other hand, earthen ridges are usually smaller and are used for crop cultivation in the zone immediately adjacent to the upper side of the line where a shallow furrow has been dug to build the ridge

(Critchley et al., 1991). In some cases, when precipitation in the area is abundant, it is good practice to build cut-off drains to safely dispose the surplus of water (WOCAT database).
Trashlines have been used to create barriers along the contours with the same aim. Weeds and crop residues are laid in bands across the slope of annual crop fields to conserve soil and water, and to incorporate organic matter into the soil after decomposition (Liniger and Critchley, 2007).

Costs

Technique	**Country**	**Cost**	**Remark**	**Reference**
Tied Ridging	Zimbabwe	330 $ to buy the equipment 250 $ to hire the equipment	$300 for new ox-drawn ridger $30 for new mouldboard plough If hiring the equipment, it cost $250 per hectare	(UNEP 1998)
Stone bunds	Burkina Faso		Increases costs if limited stone resources. Cost for transportation	(UNEP 1998)
	Ethiopia	$13.6 ha-1 year-1		(Jan N.et al., 2007)
Swales on-contour	Arizona, USA	Low cost (Brad L., 2008)		(City of Tucson Water harvesting guidance manual,2005)
Contour bunds	Syria, Ethiopia			(Critchley et al,1991) Oweis T. & Hachum, A. (2006)
	India	Approximate cost for laying contour bund is $33.66/ha		(Critchley et al,1991)
Contour ridges	Libya			(Critchley et al,1991)

Impact

Impacts	Advantages	Disadvantages	Indicators

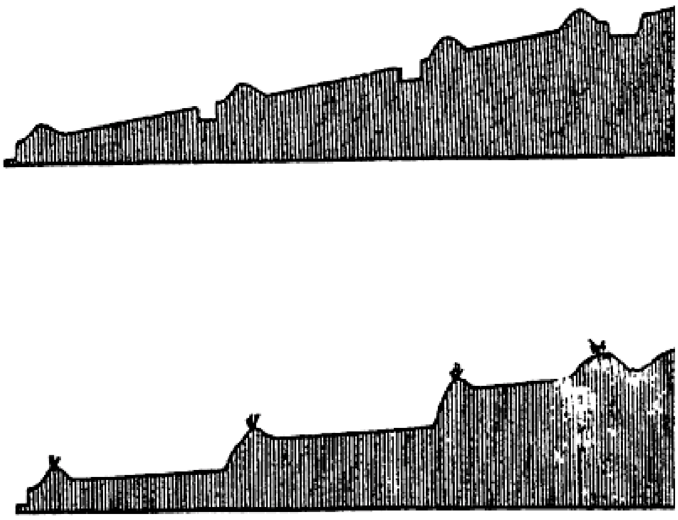
Environment	- reduces soil erosion - retains soil moisture - reduces run off		- Run off rate (m3/s) at outflow point. - Evaporation rate (%) - Soil moisture (%)
Social	- Increases food supply - Easy to adopt in many countries - Increase knowledge to the locals		- Food supply (kcal/day) - Willingness to apply the technique - Knowledge about the technique - Number of farmer adapting new technologies
Economic	- Increases crop yield - revitalize agribusiness activities - increase yields during dry periods - Save time for other economic activities - Low cost	- Increases farmers' costs for maintainance every year - time consuming and labour intensive in construction and operation	- Crop yield (kg/ha) - Famers income ($) - Area (ha) - Working hours - Cost ($)
Technical	- Simple to implement at the local level - Simple equipment - Simple to construct - by hand or by machine . - not easy to wash away even big rain (Stone bunds)	- Requires new or additional equipment. - Need external material to construct like rocks (stone bund) - Require substantial time and effort required to prepare the lands each year - Topography required - In areas with highly variable rainfall, ridges can fail due to overtopping earth contour)	- Requirement of material, tools, labour and design of technique - Time to train people to use the technique - Topography - Climate (rain fall amount)

5. In-field Water retention - Terracing

In order to be able to farm on steep terrain terraces have been build all around the world. The shapes and the design might change from place to place but the overall mechanism is always similar. In some areas they are used to discharge excess water and in some others to improve water retention. In dry and semi-dry areas terraces together with grass cover are an effective measure to control soil erosion and favor green water build-up.

In field water retention techniques refer to structures that allow soil in a cropping field to retain or store moisture for a specific period enough to cater for a dry spell. Other specific primary uses are controlling erosion, trapping sediments and increasing water infiltration. In most cases they are used to provide additional services like fodder, fertility improvement and fuel wood as well (Ngigi, 2003). Technologies are suitable for semi-arid regions were agricultural production is limited by soil moisture stress to more humid areas where there is more than adequate rainfall. Soils in this category of techniques are usually susceptible to extensive soil erosion (Ngigi, 2003).Terrain suitable for this category of technologies includes hill sides which are either steep or gently sloping to areas which are almost flat lands (WOCAT database). Examples include basic terraces such as Fanya juu and orchard terraces, benches (konsos and stone reinforced benches) and tabias (Tunisia). These structures are built with either stones or soil.

In Ethiopia and Kenya soil bunds and Fanya juus are established in the same way by embarking soil on a contour line which is laid at zero gradients and compacting it (WOCAT database). Stability is further reinforced by planting trees and grasses to increase multiple purposefulness of the structure. In Ethiopia also the Konso and stone reinforced benches are a common structure used to control erosion mainly. These



structures are built with stones along the contour and land leveling is done in between two terrace walls.

Figure 20: *Fanya Juu schemes: recently developed system (top), and later development (bottom) (Critchley, 1991)*

Level benches like those in Zhuanglang in China require very deep soils which are highly erodible and degraded, on hill side slope of 25 -35%. The benches are built from the bottom of the hillside going upwards and consist of vertical or a very steep earth riser and flat leveled bed, cropping area, with or without a small earth ridge to trap water. The down side of each bench is slightly cut to create a more gentle riser where to plant cover grass or trees to reinforce the soil. Almost similar to this technique are the orchard tree terraces with Bahia grass grown on the entire riser and also partly on the terrace beds to improve fertility and water conservation.

Costs:

Techniques	Countries	Cost (USD)	Remark	Reference
Fanya juu	Eastern and Southern Africa	$260	Labour $199Tool $63Seed $8	Liniger H. & Critchley , 2007; Okoba et al, 2006

Strip cropping	Kenya	one of the cheapest conservation practices	Cost for labourcost for fuelcost of establishing grasses and legumes in a long-term crop rotationCost for maintenance	UNEP,1998; Hatibu N. & Mahoo H. 1999; Carman D.
Soil bund and fanya juu combined with vegetation	Ethiopia	$260	Labour $199Tool $63Seed $8	WOCAT 45
Konso bench	Ethiopia		Cost for labourcost for fuelcost of stoneCost for maintenance	WOCAT 86
Stabilized stone faced soil bund	Ethiopia	$1079	Labour $170 Tool $720 Seed $30 Fertilizer $54 Animal traction $35 Harvesting $23 Cost for stone	WOCAT 55
Terraces	Tunisia	from $1 to $6/linear foot of terrace.	Plus cost for building up water way or conveyance	Carman D.
Orchard terraces with Bahia grass cover	China	$1.840/ha Maintenance $365/year/hectare	labour $840fruit seeding $350 Bahia transplant $435 Fertilizer $145 Compost $70	Liniger H. & Critchley , 2007;
Small lever bench terraces	Thailand	$275/ha maintenance $45/ha/year	labour $270 tool $5	Liniger H. & Critchley , 2007;
Zhuanglang loess terraces	China	$275/ha Maintenance $45/ha/year	labour $270 tool $5	Liniger H. & Critchley , 2007;
Nateros	Canary islands			De Graaff J. & Ouessar M. 2002
Gavias	Canary islands			De Graaff J. & Ouessar M. 2002

Live barriers	Cochabamba, Bolivia			CIAT
Traditional stone wall terrace	South Africa	$1.270/haMaintenance $160	Labour $1.250 Tool $20Crowbar stone	Liniger H. & Critchley, 2007

Impact

Impact	Positive	Negative	Indicator
Environment	- Reduces flooding - Reduces soil erosion (Fanya juu can reduce erosion by 10 to 50%) - Reduces runoff - Maintains soil moisture - Maintains soil fertility - Increases vegetation cover - Reduces evaporation	- Pests and vermin from grass strips can destroy main crops - The strip crop can compete with the main crop (Strip cropping)	- Water volume (m^3) - Run off rate (m^3/s) at outflow point. - Evaporation rate (%) - Soil moisture (%)
Social	- Easy to adopt in many countries - Well accepted and supported by people in arid and semi-arid areas. - Improve knowledge of local people. - increase food supply and nutrition		- Food supply (kcal/day) - Willingness to apply the technique - Knowledge about the technique - Number of farmer adapting new technologies

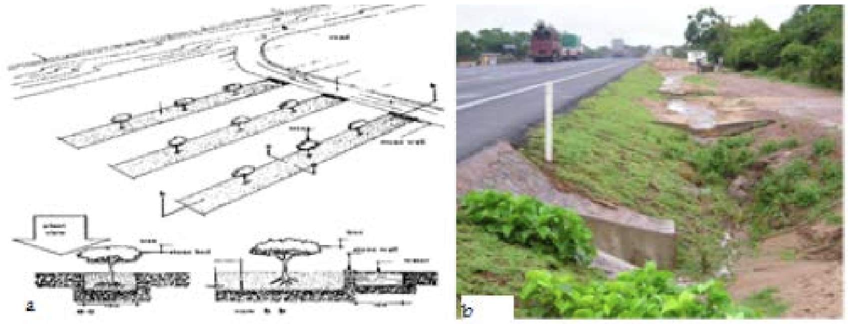
Economic	- Structures do not obstruct farm operations - The sugarcane barriers can produce 1.5 to 2 kg brown sugar per meter without fertilizer (live barriers) - Save land (no area lost because fodder is grown on bunds) - Increase fodder and wood production - Increases crop yield - revitalise agribusiness activities - increase yields during dry periods	- Labour consuming	- Crop yield (kg/ha) - Famers income ($) - Area (ha) - Working hours - Variety of crops - Cost ($)
Technical	- Simple technique - Simple equipment	- Hard to maintain the grass strips during winter. - Require closer protection and guarding. - Require regular maintenance. - Topography required	- Requirement of material, tools, labour and design of technique - Time to train people to use the technique - Topography - Extra water for maintenance of the grass strips (m^3)

6. Runoff diversion - Diversion, road run-off systems

Roads, either paved or unpaved, can be used as a rain water catchment area with the runoff being channelized off road, into fields or storage structures for multiple purposes. Techniques take advantage of the shape of a road where the crown sheds water to the road sides (Prinz and Malik 2002) (Mutunga, Critchely et al. 2001).

The category is especially suitable for semi-arid dry regions where amount and frequency of precipitation are small and very variable and can be used to store water for longer periods. In more developed economies like Brazil, Argentina and Venezuela the water is collected in specialized structures and can be used for even augmenting city water supplies and for agricultural production (UNEP 1997).
In Africa, an example where this technique has been successful for improving agricultural production in semi arid regions is in Kenya. In this case, the farmer harvests run-off from mainly the Nairobi highway tarred road, channels it through a 300m length main channel into modified fanya juu and fanya chini terraces to distribute water around the fields. Some water is also harvested from a 10 ha catchment area on the upper side of the farming plot. The embankments of the channels that distribute the water are stabilized by perennial grasses which are used for other purposes as well. The main purpose of this technique is to increase soil moisture for crop production (Mutunga, Critchely et al. 2001).
In other cases in Southern Africa the water is channeled from unpaved roads through road culverts and storm drains into either structure in category 8 (“Runoff collection and storage”), for storage or into the fields through canals and bunds systems. This water is used mainly for agricultural production (Banana production) and for livestock purposes (Searnet.org) (Mutunga, Critchely et al. 2001).

These techniques in developing countries have potential to be used for dual purposes and functions like community based management of rural roads, which are normally neglected by relevant authorities and suffer from extensive erosion. Fruit trees can also be planted alongside roads as in Brazil (UNEP 1997), to provide added nutritional value for people and livestock. Brick making and forestry related activities can also be improved using water acquired from these techniques (Nissen-Petersen, 2006b).



a. Road diversion techniques in S. America
b. Culverts on the Nairobi highway in Kenya

Figure 21: *Road diversion systems and culverts for agricultural use.*

Costs

Techniques	Countries	Cost (USD)	Remarks	Reference
Road culverts and stormdrains linked to several storage facilities	Southern Africa			Searnet
Street runoff collection	Kenya	Low cost techniques	labour cost, Tools needed (common household tool): like mattock, shovel, machete, plain/forked jembe.	"Runoff Farming" Prinz and Malik
Water harvesting in banana plantations	Uganda			Mutunga, K., and Critchley, W. 2001).
Runoff Collection from Paved and Unpaved Roads	Brazil and Argentina, Kenya	100 day labour/hectare to construct bund and channel $2.000/km stretch of paved in Argentina	The costs vary depending on the length of roadway and the characteristics of the pavement	UNEP 1998
Microbasins pathways	Arizona, USA			Mutunga, K., and Critchley, W. (2001).

Impact

Impact	Positive	Negative	Indicator

Environment	- Reduces run off - Increases soil fertility - Increases infiltration - Maintain soil moisture	- Water collected from roadways may be polluted by litter and chemical pollutants from vehicles. (Road runoff harvesting)	- Run off rate (m3/s) at outflow point. - Nutrient content, organic matter content - Water infiltration rate (%) - Soil moisture (%) - Water quality
Social	- Requires collective action - Well accepted and supported by people in arid and semi-arid areas. - Improve knowledge of local people. - Increase food supply		- Willingness to apply the technique - Knowledge about the technique - Number of farmer adapting new technologies - Active participation - Food supply (kcal/day)
Economic	- Increase fodder production - Increase farmer income - Low-cost technology - Increases crop yield(Doubled banana/pawpaw/ maize/beans yields production) - increase yields during dry periods - Save time for other economic activities	- time consuming and labour intensive in construction and operation - high maintenance costs as they are easily damaged by animals	- Crop yield (kg/ha) - Fertilizer cost ($) - Famers income ($) - Variety of crops - Cost ($) - Working hours
Technical	- Simple technology - Can be constructed simultaneously with the road. - Easy to operate and maintain. - Should be combined with some of the in situ or regional appropriation techniques to improve the effect.	- Plants may need additional water to survive in dry periods. - Keep animals away to avoid plant damage. - Requires suitable soil conditions. - located near the roads	- Requirement of material, tool, labour and design of technique - Time to train people to use the technique - Topography - Extra water for maintenance of grass strips (m3)

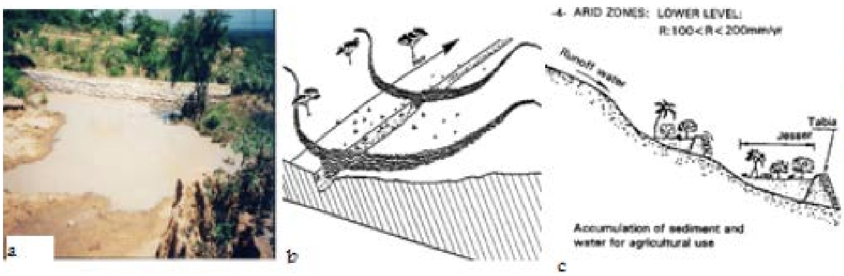
7. Controlled area drainage

The basic principle in this category is that water, is collected secondarily for agricultural purposes whilst the primary purposes are for controlling concentrated water flow during or soon after a heavy downpour of rainfall. Techniques in this category allow controlling of soil erosion, collection of fertile sediments, conserving run-off, recharging the aquifer, moisture conservation (spreading water over agricultural lands) and harnessing underground water flow in river beds for later extraction (Mengistie 1997).

These techniques are appropriate for areas that are arid to semi arid with relatively permeable soils and substrata and at times impermeable below surface structures, to areas which are generally flat with hill side slopes and in usually dry river beds or water ways (WOCAT database).

Check dams, warping dams, Gully control techniques such as gabions and gully plugs in East and Southern Africa, South America and China are techniques in this category that are used primarily to control soil erosion, water flow and gully control. They also have an added advantage of harnessing water for other purposes. Usually the dam walls, made of stones, fired bricks, bags of cement or fertilizers filled with cement, sand and brick chips, are built across a natural drainage course. In sandy or loamy soils, the walls are constructed by tree stems in combination with live plants such as vetiver grass. Combinations of walls can be done but this is mainly determined by the slope of the land and on distance between walls in the same gully depth or water way. The techniques allow sediments to collect behind the walls, slowing down water flow thus collecting it for a while to allow better infiltration to recharge underground sources. In some cases the riser are built gradually year after year, building up fertile sediments until when the gully is filled up. Deep and fertile soils are created by sediments behind the wall with fruit trees such as paw-paws and field crops like maize and sorghum can then be grown on these deep, usually fertile sediments (Falkenmark, Fox et al. 2001; Van Haveren 2004; Mwenge Kahinda, Rockström et al. 2007).
Furthermore, an infiltration basin behind a dam can be used as source of water for artificial groundwater table recharge. A reservoir behind a dam, a pond or a spoil depression are just few example of what can be used as an infiltration basin. In order to permeate and reach the aquifer the soil surface need to have a certain degree of permeability. Nevertheless, when an impermeable soil layer stands close to the surface a recharging well can be used to by pass it. Recharging wells are built in the bed of the reservoir and inject the water directly to the aquifer (UNEP, 1997). Usually recharge wells resemble a slow filtration sand bed because their base is often filled with sands and gravel to filter the incoming water. The designing phase must be careful to address problems like water quality, nature of soil layers, clogging of the pipe (Twort et al., 2000).

Sand dams and subsurface dams utilize the general principal as in the other techniques expect that these structures store water within soil, which is later extracted for other purposes. In principle sediments depositsedbehind a wall act like a medium for storing water. The systems take advantage of the hydrological characteristics of the river bed. The dam is built in a trench or ditch dug across the river or creek bed into the banks. The wall height is increased with increase in amount of silt or sediments build up behind the dam wall usually following a rainy season.



a. Check dam built sand filled bags
b. Rock dams built in succession on a water way
c. Jessours on a slope in Tunisia

Figure 22: *Check dam, rock dams and Jessours (from left to right)*

Costs

Technique	Country	Volume	Cost	Benefits	Remarks	References
Subsurface barriers	India	28,750m³	US$3750			Narain, P.; Khan, M. A.; and Singh, G. 2005.
Sand /subsurface	Kenya	2000m³	US$7500	US$1,625 /y per farmer		(Rain 2007); Foster, S. &Tuinholf, A, 2004)

sand dams/subsurface	Ethiopia	2000m³	US$4616			(Rain 2007)
Sand/subsurface dam	Brazil	2000m³	US$5034	US$8598	1US$=2 Brazil Rs (2001)	Foster, S.& □Tuinhof, A. (2004□
Subsurface dam	Burkina Faso	1,800,000 m³	133495 thousand Japanese yen			MOE (2004)
Gabions	Kenya/Tanzania					RELMA/Sida □in Kenya, (2005).□Nissen-Peterssen, 2006.
Gully rehabilitation using stem cuttings	Nicaragua		US$225			WOCAT pg.231
Checkdams	Ethiopia/Kenya/ Sudan					
Permeable rock dams	Burkina Faso		500/600 $/dam (1988)			
Warping dam	China					
Sand dams/subsurface	Zimbabwe					
Bolsa	Mexico					
Gabions	Arizona, USA					
Terraced gully	Kenya					
Sunken streambed structure	India		US$245			WOCAT pg.207
Gully healing using trash lines	Tanzania					
Gully control and catchment protection	Bolivia		US$126			WOCAT pg. 335
Gully harnessing/gully plugs	Kenya/Ethiopia					

Impact

Impacts	Advantages	Disadvantages	Indicators

Environmental	-reduce storm run off -reduce soil erosion - facilitate tree planting programs -stimulates ecological regeneration -ameliorate microclimates -raise water recharge levels -increase groundwater recharge and retention -reduce evaporation since water is under the soil -increase volume of water for abstraction -harvest sand and sediments -rehabilitate gullies -concentrate run off- reduce the slope angle-reduce slope length-trap organic matter that can be used to fertilize land	- loss of vegetation for building the structures	- Runoff rates (m^3/s) at outflow point - Reduction soil erosion - Water storage capacity (m3) - Depth of water table (m) - % Evaporation rate - Nutrient content, organic matter content - Biomass production (kg/ha)

Socio - cultural	-increase food supply and nutrition -improve health due to water availability and accessibility (sand/subsurface dams) -emergence of new social roles e.g. men collect water for sale (sand/subsurface dam) -Relief to women and children from long distances in search of water (sand/subsurface dam)-Increase knowledge to the locals -improve housing systems due to water availability (brick making)(sand/subsurface dams) -reduced pollution of water since water is covered by the sand and (sand/subsurface dams).-Supplies water throughout the year (sand/subsurface dams)-Prevents mosquito breeding grounds (sand/subsurface dams)-Prevents the possibility of drowning of children-Assured community acceptance due to community involvement	-land use rights conflicts -Water use conflicts if not well planned (sand /subsurface dams)- collective action for water management	Food supply (kcal/day - Occurence of diseases Division work by gender Knowledge about the technique - Willingness to apply the technique - Knowledge about the technique - Water quality
Economic	- revitalize agribusiness activities (cash crop and livestock production) -increase yields during dry periods -Save time for other economic activities (e.g. sewing, marketing) -silt can be used for fertilizing farms -inexpensive technology -low construction cost due to high level of community involvement -require locally-available materials. -diversified uses e.g. domestic , small scale irrigation (sand dams)	-time consuming and labour intensive for construction -high cost of repair and maintenance	- Famers income ($) - Cost ($) - Crop yield (kg/ha) - Construction cost ($) - Working hours (hours) - Fertilizer cost ($) - Material cost ($)

Technical	- Simple to construct	-requires technical input in siting- improper construction leads to seepage (sand dams)-require specific soil types soil(sand dams) -risk of salinisation(sand dams)	- Requirement of material, tool, labour and design of technique - Time to train people to use the technique

Costs of aquifer recharging

Techniques	Countries	Cost	Remark	Reference
Recharging wells	Tunisia	IRR = 13.3%; NPV (with 10.8% discount) 0.79 MDT (Tunisian Dinars); IRR of 18%		Ouessar et al. (2004), Fleskens et al. (2002)
Artificial aquifer recharge	Argentina	construction costs: USD 0.20/m3; maintenance: USD 248 /yr		UNEP (1998) - SATFALAC

Impact

Impacts	Advantages	Disadvantages	Indicators
Environmental	Recharge aquifer Steady baseflow	increases soil salinity (recharge wells)	
Socio - cultural			
Economic	low cost technology (artificial GW recharge)	heavy investment required - high labour requirement (recharge wells) regular maintenance required (artificial GW recharge)	
Technical	Need expert advise	The well is easily silted	

8. Run-off collection and storage

Runoff collection in little reservoirs are implemented throughout Africa and are present in many shapes. A final typical recipient could be either a closed artificial tank or an open-air impoundment, where the water is concentrated during the rainy season for a later re-use.

As the name suggest the structures in this category are mainly run-off collection and storage techniques. The basic criteria in this class is that structures are at the lowest point in the locality, so rainwater runoff flows naturally towards the water reservoir by gravity (Nissen-Petersen 2006). The category forms a basic component in any water harvesting conceptual definition as it comprises of the structures that form the link between a catchment area and the intended end use of the water (Falkenmark, Fox et al. 2001). Techniques in this category range between underground water storage tanks, cisterns to small surface earth dams to ponds and natural water pans. Apart from storing water for dry spells and depending on size, for water

supply and irrigation in the dry season use, these techniques can also act as flood control mechanisms, collecting sediments, reducing erosion and uncontrolled runoff and recharging the groundwater.
The category is suitable for a wide range of habitats from those that are either dry or arid to those that receive high amounts of rainfall, from gently slopping land to high altitude areas with more or less a steep slopes. Some of the techniques can be in-field whilst some can be on the homestead (on-farm) or quite a distance from the homestead (off farm). Location of the techniques is quite useful in sub-classifying these techniques. In most cases structures do collect water that can be used after the rainy season in the dry periods (Subgyono and Pawitan 2007).

On site runoff collection systems usually are tanks and cisterns. The systems vary in sizes depending on quantities of water to be stored. Structures can be either under or above ground, covered or uncovered, depending on space, technology, investment capacity and forms of extracting the water. Position on the homestead depends on use and whether they are meant to store rain water or rooftop water. Ground tanks can either be plastered with cement, or by using cheaper materials like ant hill soils, lined with burnt bricks and at times reinforced with mesh building wire. In some cases plastic sheet lining is used to prevent seepage and usually this is cheaper than the plastering. These kinds of structures can be used to store water for longer periods of time. In dry countries like in Tunisia and morocco and also in parts of sub sharan Africa special tanks usually referring to cisterns are built to harvest runoff from rock catchments (rock outcrops or other non-porous surfaces) The water is usually used for domestic purposes and for watering vegetable gardens and fruit trees on the homestead (Nissen-Petersen, 2006a).

Off site run-off collection and storage structures are usually open structures which usually collect water for livestock and agricultural purposes only. These structures can be built or implemented in natural depressions. Micro dams, earth dams, Ndiva, Eris (Indonesia) and pools are manmade structures built on, or along small streams to harvest run off. In some cases like the Ndiva the structures are fed by canals and other structures like those in category 6 (“Run-off diversion”). Water pans usually form naturally in natural depressions where the water table is high. In some cases water pans can be modified by wild animals like Elephants which trample on them and scope out sediments making them deeper. Ponds like hafirs and mahafurs are very common in dry arid regions like Sudan were they are dug into natural depressions provide water for extreme dry land communities. Channel reservoirs in Indonesian highlands are built in succession of each other along a stream are a common technique in highlands in Indonesia (Nissen-Petersen, 2006a).

The Manama technique is an infield contour based technique that is quite a common technique used in the dry South Western parts of Zimbabwe (Nyati, 2008). For this technique an underground earth tank built from local materials and walls made of rammed earth are built along a dead contour to store runoff water which can be used in-field for agricultural purposes (Practical Action). However this technique is labor intensive and usually impractical as a dead level contour requires specialized skills and techniques to make it, attributes which are usually not in favor of small scale farmers (Zaag 2010)

a. Underground rectangular plastic lined tank; b. A dead level contour with a Manama infield tank; c. An underground tank being built; d. A water pan on a natural depression

Figure 23: *Runoff collection and storage in different shapes. The reservoir can be either open, buried underground or made of concrete.*

Costs

Techniques	Countries	Capacity	Cost	Benefits	Remark	Reference
Earth dams	Tanzania	3000m³	US$30,000		93 metric tonnes of food	CARE Tanzania(2008)
Earth dams	Kenya	15,000m³	US$5,000			Mati (2000) in Malesu□ Et al,, 2006 link
Earth dams	Kenya□	□□□9000m³□□□	US$2557(Animal) US$3196 (manual) US$4261(tractor) US$8521(crawler)	US$2376/y-1		RELMA/Sida □in Kenya, (2005).□Nissen-Peterssen, 2006. Link
Charco dams	Kenya	500m³ □	US$658 US$527(manual) US$395 (tractor)	US$132/y-1	Exchange Rates 1US$=Ksh76 (in 2006)	RELMA/Sida in Kenya, (2005). Nissen-Peterssen, 2006. Link
Embung (small dams)	Indonesia					
Lacs Cllonaire (Hill dams)	Tunisia					
Hill Side dams	Kenya	500m³	US$438 (manual) US$351(tractor) US$263 (oxen)	□□US$132/y-1	Exchange Rates 1US$=Ksh76 (in 2006)	RELMA/Sida □in Kenya, (2005).Nissen-Petersen, 2006.□
Valley Dams	Kenya□	5,000m³	□□US$6593 (crawler) □US$2198 (manual)□ US$1758 (tractor)□ US$1319 (oxen)	□□ US$1320/y-1	Exchange Rates 1US$=Ksh76 (in 2006)	RELMA/Sida □in Kenya, (2005).Nissen-Petersen, 2006□

Khadins/Dhora (hill dams)	India	18,000m³		US$630/ha		Narain, P.; Khan, M. A.; and Singh, G. 2005.
Pan	Kenya					RELMA/Sida in Kenya, (2005).Nissen-Petersen, 2006
Haffirs(deep pans in Sudan)	Sudan					RELMA/Sida in Kenya, (2005).Nissen-Petersen, 2006
Haffirs	Kenya					RELMA/Sida in Kenya, (2005).Nissen-Petersen, 2006
Mahafurs(pans)	Tunisia					RELMA/Sida in Kenya, (2005).Nissen-Petersen, 2006
Ponds (manua)	Kenya	100m³	US$132	US$27/y-1	Exchange Rates 1US$=Ksh76 (in 2006)	RELMA/Sida in Kenya, (2005).Nissen-Petersen, 2006
Ponds (Nadi)	India	1,200m³	US$1860	US$1320/y-1		Narain, P.; Khan, M. A.; and Singh, G. 2005.
Rock catchment	Kenya					Nissen-Petersen, (2006)
Weirs	Kenya					Nissen-Petersen, (2006)
Pans/ Ndiva	Ethiopia/Kenya/Tanzania					Nissen-Petersen, (2006)
Zabo	Nepal/India					ICIMOD,2009
Atajados	Bolivia	1300m³	US$5000			Goetter Johanna(2010)
Small dams and pools	Bolivia Ades		US$1400			Goetter Johanna(2010)
Johads	India		US$400-1000			Arsenault, et. al 2007
Tanka	India	35m³	US$500	US$39/y-1		Narain, P.; Khan, M. A.; and Singh, G. 2005.
Manama(dead level contour reservoirs)	Zimbabwe	20m³				

Birkas	Kenya	162m³	US$973		Exchange Rates1US$=Ksh 76 (in 2006)	Nissen-Petersen, (2006)
Hemispherical tanks(briks)	Kenya	22m³	US$749			Nissen-Petersen, (2006)
Hemispherical tanks(anthill soil, lime and cement)	Kenya	60m³	US$1752			Nissen-Petersen, (2006)
Tanks	Ethiopia	14.8m³	US$145		1US$=8.2 Birr (2002)	Nuge,H. and Kimeu, P.M (2002).
Tanks	Kenya	12m³	US$12		1US$=75 (2002)	Nuge,H. and Kimeu, P.M (2002).

Impact

Impact	Advantages	Disadvantages	Indicators
Environmental	-collect run off -reduce storm run off -reduce soil erosion -harvest sediments - facilitate tree planting programs -facilitate sprouting of vegetation naturally -ameliorate microclimates -raise water recharge levels -increase groundwater recharge and retention	-risk of clogging water source by silt -high loss to evaporation in open reservoirs	- Runoff rates (m^3/s) at outflow point - Reduction of soil erosion - Nutrient content - Water storage capacity (m3) - Depth of water table (m) - Biodiversity of plants
Social	-increase food supply and nutrition -improve health due to water availability and accessibility -emergence of new social roles e.g. men collect water for sale -Relief to women and children from long distances in search of water -Increase knowledge to the locals -improve housing systems due to water availability (brick making)	- unpopular and seldomly used - create breeding grounds for mosquitoes and snails -water pollution/contamination by animals/chemicals from -Risk of children and animals drowning -land rights conflicts-requires collective action	- Food supply (kcal/day) - Willingness to apply the technique - Knowledge about the technique - Division work by gender - Occurrence of diseases - Conflicts over land use

Economic	-revitalize agribusiness activities (cash crop and livestock production) -increase yields during dry periods -Save time for other economic activities (e.g. sewing, marketing) -silt can be used for fertilizing farms -clay/anthill soil used to reduce costs(tanks/Manama) - roofing used to reduce evaporation (tanks/Manama)	-time consuming and labour intensive in construction and operation - expensive to construct-high maintenance costs as they are easily damaged by animals	- Crop yield (kg/ha) - Construction cost ($) - Working hours (hours) -Material cost ($) - Maintenance cost ($)
Technical		-requires special skill for design and construction -easily damaged by animals -easily destroyed by underground flow -unsuitable in sandy soils if no lining is used -easily destroyed by underground flow	- Time to train people to use the technique - Requirement of material and design of technique

9. Direct Infiltration

Direct infiltration is probably the simplest technique that can be implemented in order to control soil moisture and make an optimal use of it. It implies the use of different systems of ditches and furrows in order to retain rainfall and favor lateral infiltration towards the soil zone explored by the crop roots.

The guiding principle for this category is that rainfall is conserved directly in the cropped area or pasture land when it falls (Ngigi 2003). The techniques allow conservation of moisture in the field by collecting surface runoff thereby recharging groundwater, and as a source of irrigation for crops (especially garden crops) (Subgyono K. 2007). These techniques are the simplest and cheapest forms of water concentration and usually based on indigenous and traditional systems. They can be practiced in almost all land use systems so long as there is need to provide excess moisture for a plant especially for wet-season dry spells (Ngigi 2003). Additional values of these techniques are to reduce run-off, erosion and excess leaching away of nutrients. Although the technique can be used in a wide variety of land use systems and varied types of soils, they are less effective in coarse grained soils with a high hydraulic conductivity (Ngigi 2003).
Techniques in this class are in essence a wide variety of combinations of ridges, furrows, trenches, pits which are at times incorporated with buried manure and compost or crop stover (Mutunga K. 2001). Examples including the matuta or sweet potato ridges and Kilimo chamfuno used in East and Southern Africa, and a wide variety of infiltration pits also used in Asia and many parts of sub Saharan Africa (Subgyono K. 2007)

a. The Matuta (sweet potato ridges)
b. Infiltration pits or ditches in a field

Figure 24: *(From left to right) Matuta ridge system and infiltration ditches*

Costs

Techniques	Countries	Cost	Remark	Reference
Matuta	East Africa			Prinz, D. And Malik, A.H. (2002)
Kilimo cha mfumo (pattern farming)	Tanzania			Critchley, W. (1999)
Guimares Duque	Brazil, Argentina, and Paraguay			
Haveli	India (Madhya pradesh)			Prinz, D. And Malik, A.H. (2002)
French drains	Arizona, USA			Philips, A.A. (2005)
Branched French drain	Arizona, USA			Philips, A.A. (2005)
Vertical French drain	Arizona, USA			Philips, A.A. (2005)
Infiltration ditch	Indonesia			Subagyono, K. And Pawitan, H. (2008)
In-situ compost cultivation or pattern farming (kilimo cha mfumo)	Tanzania		400 person days / ha	Mutunga, K. and Critchley, W. (2001)

Impact

Impacts	Advantages	Disadvantages	Indicators
Environmental	- Increases groundwater recharge - Collects surface runoff - Increases water moisture - Reduces soil loss	- Root damage by decomposition process (pattern farming)	- Water storage capacity (m3) - Runoff rates (m^3/s) at outflow point - Soil moisture (%) - Reduction soil erosion

Socio – cultural	- Increases food supply (pattern farming) - Improves knowledge for local people - Easily adopted (pattern farming)	- Requires collective action to construct (french drain, matuta)	- Food supply (kcal/day) - Knowledge about the technique - Number of farmer adapting new technologies
Economic	- Increases crop yield (pattern farming) - Increases income - Reduces fertilizer cost (in-situ compost)	- Additional cost for labour, construction and maintenance	- Crop yield (kg/ha) - Fertilizer cost ($) - Famers income ($)
Technical	- Simple to construct (pattern farming) - Can be grown for different crops (pattern farming) - Provide water for irrigation (infiltration ditch)	- Special skills for design and maintenance - Need for external material input (stones, rocks,gravel,etc) (french drains)	- Requirement of material, tool, labour and design of technique - Time to train people to use the technique - Biodiversity of plants - Water volume (m^3)

Proposed toolbox for Impact assessment

Stakeholder analysis

Stakeholders play an active role in the practice of soil and water conservation including water harvesting projects. In principle, the criterias for the choice of stakeholders could be included as follows:

1. Extent of stakeholders' influence on the project
2. Level of stakeholder's knowledge
3. Enthusiasm of stakeholders
4. Communicative skills of stakeholders
5. Integrity of stakeholders

The most important goal of the stakeholder participation is to generate support for the project instead ofobtaining knowledge. The stakeholders have certain expectations about their participation, for example :

1. their contribution from the early step until the end product
2. their expertise and share it with others
3. their knowledge and application

The listing and classification of stakeholders is usually presented in a tabular format (see Appendix). Listing the different stakeholders enables us to understand their relationship with the project such as their function (interest), their power (e.g. ownership or control of assets) and the impacts of their involvement in the project.

The common categories for the stakeholders classification are :

1. Primary stakeholders : individuals, households or organizations who are directly involved in the whole process of water harvesting project (establishment, maintenance, etc)
2. Secondary stakeholders : individuals, households or organizations who are providing tangible or intangible inputs, or dealing with the outputs or supporting the project. This group may include goverment and non-government organizations who have an interest in the project or control over the financial. This could include agricultural extension worker, sectoral agencies, banks and environmental NGOs.
3. External stakeholders : individuals, households or organizations who are indirectly involved in the project. They may include landless people in the project area, seasonal farm labours, wildlife support groups, etc.

The list and classification of stakeholders, eventually, is very important to determine the key stakeholders of the project. The groups of key stakeholders will be the focus of the project and they have high influence on the success of the project.

Table 13: *Proposed Stakeholder Analysis matrix for adoption and upscaling of WHTs*

Class	Stakeholders	Interest	Power	Impact
Primary	Farmers and Households	· Food security · Water security · Increased crop yield · Improved income	· The impact on the upscaling of the project (the power of feedback and choice) · Local resources (labor, materials,local knowledge) · Ownership · Maintenance of the WHT	· On the future direction of WHT

Secondary	Community	· Food security · Water security · Increased crop yield · Improved income · Increased employment · A kickoff to rural development	• Collective decision making • Power of the mass • Traditional knowledge/decision management • Influence on collective actions.	· Adoption/Rejection
Secondary	Traditional Leaders	· Keeping the privileges · Image of a good leader · Food security · Gifts · Rural development of the community · Status	· Decision making · Influence the public opinion · Spatial distribution	· Adoption/Rejection · Initial approval of the project · Spatial distribution
Secondary	Extension Workers	· Job security · Learn new techniques · Develop your own region (if local) · Status	· Skills · Facilitating · Mediation (local languages) · Local social network (connected to remote areas)	· Inclusion of hard to reach areas · Support to the project staff, horizontal-vertical upscaling · Gives feedback in behalf of the community/farmers
Secondary	NGOs	· Donor funding · Knowledge and dissemination of information · Image (status) · Solve the food/water crisis	•Networking •Political influence (the funding/investments are passing through the NGOs)	· Spatial distribution · Power to determine the overall outcome of the project · Cooperation with the project · Determine the pace of the project (slower/faster)
Secondary	Donors	· Rural development · Good relationships · The image of the donor	·Political ·Financial control	· Existence of the project
Secondary	Governments	· Rural development · Knowledge (new technologies) · Image (good political image) · Good relations with outside governments and international NGOs	· Selection of beneficiary communities · Accepting partnering organizations · Policy making · Maintaining security and stability	· Facilitation · Supporting · Approval and implementation · Knowledge generation by approving the project · Service delivery through the key ministries

Secondary	MetaMeta/WAHA RA Research Institution	· Knowledge generation · Job creation · Image · Research · Networking · Rural development	· Determine the goals and choices for the project · Project management (selection of organisations to work with or not to work with, fund rising)	· Determine the directions and focus of the project. For instance : spatial, technological and temporal directions.
External	Ourself (group B806)	· Learning experience, networking · Knowledge · Credits (9 ECTS) · Recognition by the commissioner	· Creating multidisciplinary knowledge · Information generation	· Influence on choices of WHT selection

Environmental Impact Assessment

Environmental impact assessment (EIA) is a critical process designed to examine the effects of a project or a programme on the environment. The overall goal of an EIA is to ensure that decisions on the project activities under consideration are environmentally and socially sound, sustainable, and acceptable (Roe et al., 1995). The process is conducted in order to identify, predict and evaluate the foreseen impacts on the environment in advance, that result from implementation of the proposed project (Roe et al., 1995; Damtie and Bayou, 2008). In addition, EIA tries to find out ways of mitigating measures of the adverse impacts and alternatives to these projects. In this case, the negative impacts are eradicated or minimized while the positive ones are maximized (Roe et. al 1995). Certain strategies are adopted in order to minimize environmental and social impacts. Some of these strategies may include avoidance, compensation and prevention.

In some countries such as Ethiopia, Rwanda, Sudan, Uganda, Egypt and Kenya, EIA can at times be integrated with social impact assessment (SIA), strategic impact assessments (SEA) and risk assessments (Damtie and Bayou, 2008; NBCBN, 2005). EIA generates a baseline data for monitoring and evaluating the impacts during the project cycle and provides information on social, environmental and economic effects of the project activities which are used to guide policy makers, planners, stakeholders and the government agencies in making sound environmentally, socially and economically sustainable decisions (Damtie, M and Bayou M, 2008; NBCBN, 2005; Roe et al., 1995). These objectives are achieved through engaging a processes-oriented, multidisciplinary and interactive group of experts that has a better understanding of the linkages between social, economic, environmental and political systems of the country(ies) in question. This group is also capable of eliciting full participation of all the stakeholders who are affected or can affect the project (Damtie and Bayou, 2008; NBCBN, 2005; Roe et al., 1995).

Projects may vary on the extend of impacts, of which some of them may require environmental impact assessment and some do not require. However the choice of a project approval depends on the individual country's relevant environmental management authority and legislature. The following list provides an overview of some types of projects which generally do require an EIA: (Roe et al, 1995):

1. Projects that may cause significant change in renewable resource use;
2. Projects involving substantial changes in farming or fisheries practices;
3. Water resource projects such as dams, irrigation, and watershed development;
4. Infrastructural development;
5. Industrial projects;
6. Extractive industries;
7. Waste management and disposal.

In our case, the development of sand/subsurface,/earth dams and other water structures falling under categories 7 and 8 may require a preliminary EIA to be conducted. Although, we find more positive impacts than negative impacts, there might be a different view based on the countries' policies and structures.

The use of GIS in impact evaluation and assessment

The use and integration of a GIS (Geographical Information System) has become very popular in environmental sciences as it allows the user to capture, store, process and present spatial data (Burrough and McDonnell, 1998). This also makes it possible to combine different sources of data and bring them together in one model. A GIS works with layers of various data sources which can be laid on top of each other. This makes it possible to map and model the individual contribution of each layer to the outcome.

Examples of data often integrated into a GIS:

- Soil maps
- Topography (slope, aspect)
- Rainfall data
- Drainage data

For impact assessment, the use of GIS can be very useful as it relates the "what" question to the "where" question. In this way GIS does not only show the user what and how high the impacts will be of a certain proposed measure (e.g. in this case the implementation of a water harvesting technique), but also shows where these impacts will occur. GIS can be designed in a variety of spatial sizes, depending on the requirements of the user. For example UNEP (2005) has developed a potential rainwater harvesting map for the whole of Africa, in which the suitability for different countries and locations are compared. On the other part of the spectrum Ramakrishnan et al. (2009) have developed a similar product for use in the Kali sub-watershed in Gujarat, India. For the criteria of rainwater harvesting potential in Africa, UNEP (2005) selected were rainfall, topography, soils, landuse and population density. Based on these criteria, they developed a set of specific criteria for the creation of a number of thematic maps (evapotranspiration, mean annual rainfall, crop growing periods, topography etc.) that were combined to obtain the potential in Africa for individual water harvesting techniques (UNEP, 2005).

It is obvious that a GIS can also be used as an evaluative tool, in which local measurement data are used in a GIS after a certain WHT has been implemented in a certain area. In this way, the user is able to map and check whether the implementation had the desired effect, and whether any undesired effects had occurred.

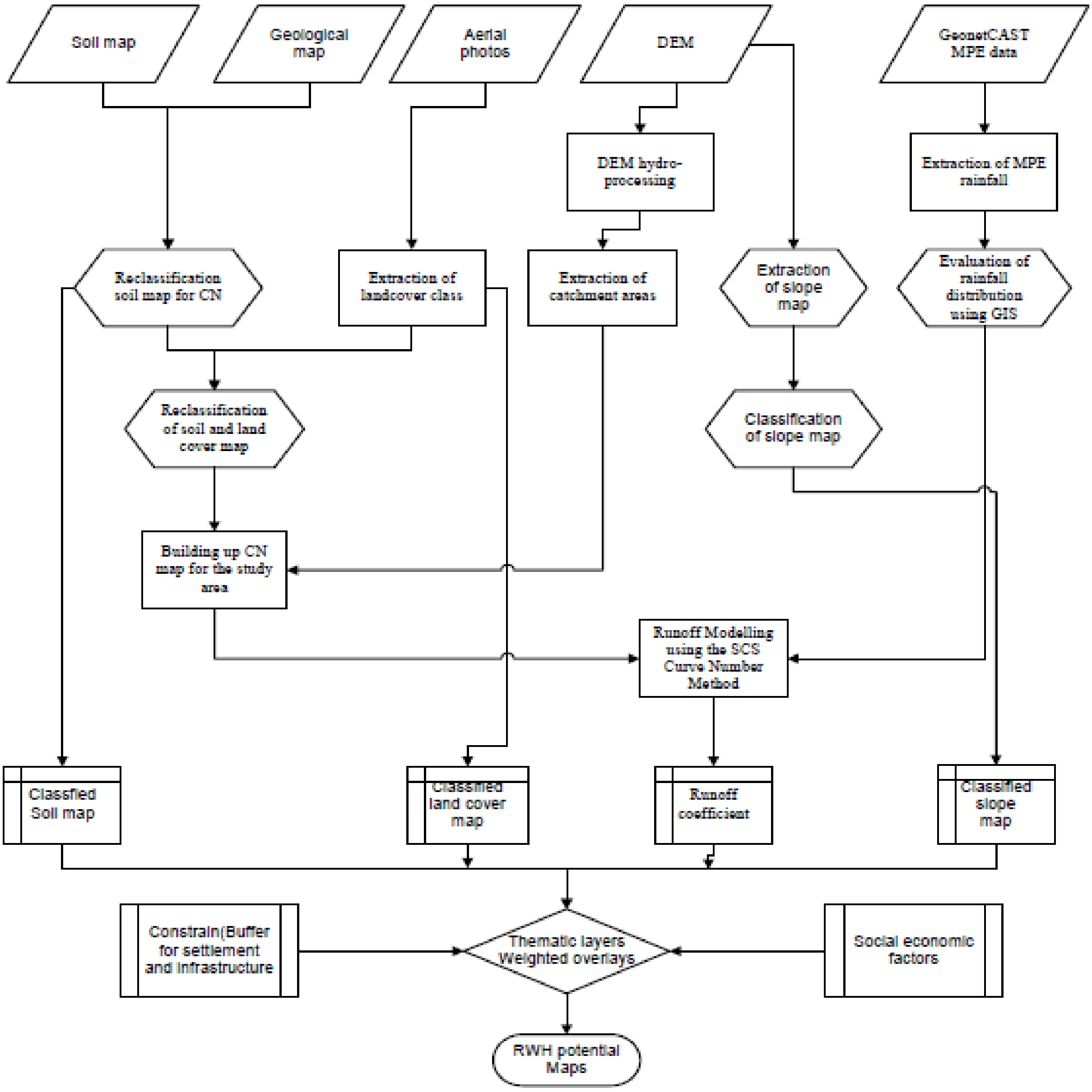


***Figure 25**: typical example of a GIS work flowchart (Munyao, 2010).*

However, the use of GIS may require a lot of input data, which may not always be available. Some of this data may not come in the required quantities, other data is too general, and some data might not be available at all (RELMA, 2005). Although this lack of representative data cannot be solved in non-GIS situations, it can be overcome with the use of a GIS. With the use of geostatistics and spatial interpolation, discrete point data can be converted to continuously varying rasterdata.
In this way it becomes possible to spatially generalise with a relatively high level of certainty. Also, if data is completely absent, the use of satellite imagery (remote sensing) can still resolve and extract data such as topography, landuse, vegetation and soil moisture (Lillesand et al., 2004). This is especially useful for very remote areas.

Cost Benefit Analysis

Cost benefit analysis is a tool that can be used for decision-making in order to measure and compare cost effectiveness of different WHTs. The tool is used to reconcile the timing of benefits and costs since they do not necessarily accrue at the same time(Callan and Thomas , 2000). As the costs and benefits are attained at different times, the cost and benefit estimates have to be adjusted to account for the fact that the value of money is not constant over time. According to De Graaff and Kessler (2009), cost-benefit analysis is used throughout the project cycle in order to assess different aspects of project such as technical, managerial, administrative and organisational, commercial, social, financial, economic, and ecological and environmental. They proposed a general sequence of analytical steps in conducting cost benefit analysis as shown below:

Table 14: *Analytical steps to conduct a cost-benefit analysis*

1.	Identify different WHTs	7.	Determine an appropriate time horizone
2.	Identify evaluation criteria	8.	Discount future effects to present value
3.	Identify effects (costs and benefits)	9.	Discuss where appropriate, income distribution aspects of benefits and costs in terms of Net Present Value, Internal Rate of Return and Benefit Cost.
4.	Quantify costs and benefits	10.	Conduct sensitivity analysis
5.	Do valuation , including shadow pricing (monetize)		Identify policy implications

De Graaff, and Kessler (2009)

Identify Costs and Benefits evaluation criteria for water harvesting implementation.
In this project, some of the following criteria were identified which include:
(i) Direct costs (inputs): man-days to construct and maintain WHTs, land use and value, cost of tools, raw material (local available or imported);
(ii)Direct benefits (outputs): increase in grain and livestock production, environmental improvement (soil, air, water quality), soil erosion control, transport cost, increased water capacity, increased biodiversity, cost for pesticide (chemical tillage);
(iii) Indirect costs and benefits: improved health, food security, welfare, improved housing system due to water availability, time saved for other economic activities;

Quantifying cost and benefit: by literature review or collect data from local market price/ local people

Discounting: intended to calculate all future effects (present value of costs and benefits). It also helps in capturing the discounted values of costs and benefits in terms of Net Present Value, Internal Rate of Return and Benefit Cost.
Computation of the above indicators will involve the following steps:
The discount factor (DF)for year t at an interest rate i equals: $1/(1+i)$

$$PV = FV_n \frac{1}{(1+i)^t}$$

a) <u>Present value (PV)</u>
FV where is the future value in year n
Net Present Value (NPV) is the difference the present value between benefits and costs over time i.e. NPV = B* - C*
<u>b) The Benefit / Cost Ratio (B/C)</u> is the ratio between benefits and costs.
B/C ratio = B* / C*
<u>c)The Internal Rate of Return (IRR)</u> is interest rate at which Present Value Cost is equal with Present Value Benefit (i.e., at which NPV=0)
B* = C*
Whereby B* = discounted benefit and C* = discounted cost

The discounted benefits and costs are compared (Net Present Value, Internal Rate of Return, Benefit Cost Ratio). NB:The most important indicator is NPV.

Sensitivity analysis: Due to the fact that we are uncertain of what may happen in future in terms of costs and benefits, as a result of markets, prices, wages and other inputs and outputs, sensitivity tests are carried out to calculate costs and benefits of current WHTs as well as NPV and IRR for the foreseen variations in the above variables.

Multi-criteria analysis

According to CIFOR (1999) "Multi Criteria Analysis (MCA) is a decision-making tool, developed for complex multi-criteria problems that include quantitative and/or qualitative aspects of the problem in the decision making process." MCA is used to compare and rank alternative options taking into account and evaluating their consequences too. In evaluating the most preferable WHTs, MCA could be used to identify the most appropriate techniques per given ecological zone based on a set of criteria proposed in this report or based on other more local criteria. In this case, WAHARA (i.e. the decision maker), will have a clear view on the most preferred techniques to implement in any particular region. MCA in general invokes 4 steps: identification of criteria, scoring, weighting and combining the weights and scores for each option to derive an overall value (ODPM, 2005).

In this project, five general criteria were identified that all influence the choice of implementing particular water harvesting techniques in any of the four countries. More specific criteria can be further developed in each of these five criteria based on the aspects of concern.

Table 15: *Different indicators for the different impact assessment criteria*

Criteria	Indicators	
Social-cultural impacts	-culture -labour for water harvesting -gender roles -institutions -political stability -populations	-religions -health -livelihoods -policies -social structure -age structure
Environment impacts	-water quality -damage to the environment -hydrological benefits/consideration	-soil quality -improvements -biodiversity
Economic impacts	-investment costs of WTHs -monetary gain activities	-markets -existing/potential agribusiness
Technological impacts	-available of knowledge -technical structure	-material -applicability/replicability
Agro-ecological condition	-climate variable -topography	-soil types -soil depth and stability

The other three steps can be done by experts and stakeholders (locals) who are able to give scores and enable weighting for the proposed WHTs in terms of the criteria proposed above or others developed locally depending on the circumstances. The most preferred techniques will be ranked in order with the most preferred ones chosen for implementation.

CONCLUSIONS AND RECOMMENDATIONS:

Based on the results and analysis of the study this section highlights the conclusions and recommendations.

1.Water harvesting technologies are not new to these area as the list in table 16 shows. The list shows that there are many in use WHTs that are inherent to different communities. However, the results show similar techniques exists in different countries but have been tailor made and developed to suit specific environmental conditions. For example terraces are not inherent to only one specific country, but they can be found around the continent in different shapes and designs.

2.From the country reviews, and list of WHTs (see appendix) based on the in country conditions including soils, climatic conditions (temperature, precipitation, evapotranspiration, wind and humidity), topography, socio-economic conditions and current and land tenure system we can conclude that not all WHTs can be universally applied in different agro-ecological zones. By using the country reviews and the WHTs impact analysis including the costs and benefit it easier to select and implement appropriate WHTs for specific zones. For instance it becomes easier to decide on not to use a Jessour from Tunisia in Zambia because the technique requires very arid hill sides and seasonal small streams. On the other hand the fog harvesting technique can be used in any area where there is fog even in arid areas. This is also illustrated in the Table 13 below were WHT are classified according to where they are used where they have potential to be implemented according to specific regions.

Table 16: *Table showing the techniques that are already in use in the different agro-ecological regions*

Categories	Agroecological Zones			
	Burkina Faso	Tunisia	Zambia	Ethiopia
Rainfall	400-700	< 200	500 – 1400 mm/year	200 – 1200 mm/year
Temperature	17-40 °C (average 29.3 °C)	7-33 °C (average 19 °C)	4 – 32 °C (average 19 °C)	16 – 27.5 °C (average 23.3°C)
Evapotranspiration	2002 mm/year	1487 mm/year	1488 mm/year	1532 mm/year
WHTs in use	stone bunds, permeable rock dams, Earthen Bunds, Fosse fumière (compost pit), zai , contour stone bunding, manure+termites, composting associated with planting pits, demi-lunes	Meskat, Eyebrow for forestry Jessours, Tabia, floodwater irrigation, terraces, Lacs collinaire, negarim, , mgouds ,earth dams Contour ridges,, contour bunds,	Runoff water collection in dams, conservation farming, manama (dead contour underground reservoir)	Korbe, trashlines, negarim, semi-circular bunds, trapezoidal bunds, contour bunds, stone bunds, fanya juu, konso bench, sand / subsurface dams, check dams, pans/ndiva, cistern, earth dam, eye brow, elevated ponds

From the study conducted several impacts were identified and indicators outlined for them. The impacts were classified as environmental, social, economical and technical. Some of the impacts were universal across most categories with some being specific for a particular category. Indicators to assess the occurrence of positive impacts were also developed and were mainly based on aspects that a small holder farmer can identify and measure. The table below shows the most common negative and positive impacts and indicators.

***Table 17:** Most common positive and negative impacts and indicators for assessment*

Class	**Positive**	**Negative**	**Indicators**
Environmental	-Improved water infiltration. -Improved soil fertility. -Reduced run-off. -Improved moisture retention. -Reduced soil erosion	-Decrease in environmental quality. -Loss of vegetation. Increase in pests/vermin.	-Soil erosion. -Nutrient content. -Environmental quality. -Water infiltration rate (%) -Occurrence of pests and -weeds. -Runoff rate (m3/s). -Soil moisture (%)
Social	-Easy to adopt. -Improved food supplies. -Improved livelihoods. -Social cohesion	-Not suitable for densely populated areas. -Conflict (land, people and water	-Food supply (Kcal/day). -Adoption. -Conflict. -Increased knowledge on the technique.
Economic	-Increased incomes and savings. -Technologies and usually cheap to implement.	-Labour intensive. High costs of maintenance.	-Farmer's income ($) -Crop yield (Kg/ha) -Construction costs (S) -Working hours (hours)
Technical	-Designs are easy to implement.	-Specific materials needed at times. -Suitable and precise topography. -Require special skills for design. -Time consuming.	-Requirement of materials, tools, labor and design of technique. -Time to train people to use the technique

Apart from the impacts in the table above, costs are of a major importance of determining what types of WHTs can be adopted and or upscaled within a particular region. The costs figures used in this report were obtained from various literature sources and included mainly labor, land and material costs. These costs are varied and are influenced by a lot of factors and differ from country to country and from region to region; as could be seen in the results and analysis. Coming up with a standard cost for the different agro-ecological zones was not possible. However we conclude and recommend that a standard way of using man days could be used as a standard for estimating costs of implementing WHTs in different countries and agro-ecological zones.

In this study we combined certain WHTs into categories and included some techniques that are not entirely WHTs. This was in a bid to highlight that different WHTs cannot be used in isolation with other agronomic farming techniques and in isolation with related WHTs as well. For instance, combining improved drought resistant seeds with certain moisture conservation technologies increases resilience of communities to issues of food insecurity and climate change. Also aspects like ecosystems and livelihoods should be considered as part of Climate Smart agriculture approaches (Critchely 2011). Therefore a systems approach is necessary when designing and implementing WHTs for development programs.

Other important factors necessary for the successfulness of adoption and up scaling of WHT including providing incentives to communities, improve knowledge exchanges between farmers and between farmers and external stakeholders by supporting extension workers and improved land tenure security. Close coordination between different implementing institutions should be strongly managed and monitored to avoid dual implementation and wastage of resources. It is also important to note that techniques are more effective when used in the wet season, so as to cater for seasonal dry spells.

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APPENDICES

APPENDIX ETHIOPIA:

1. Agro-climatic Zones

Traditional Classification

Ethiopia is traditionally divided into five climatic zones based on elevation and temperature. Each of the climate zone exhibits unique rainfall pattern and is under agricultural production systems. Most of the agricultural activities are concentrated in the highland zones (Dega and Wyena Dega zones) while the semi-arid and arid lowlands (kolla and Bereha) are predominantly under livestock keeping in agro-pastoral or pure pastoral production systems.

S/No	Eco-zone	Altitude (m)	Rainfall (mm)	Temp (^{o}C)	Activity/crops
1.	Wurch (cold highlands)	>3200m	900-2200	11.5	Barley (frost forms at night)
2.	Dega(cool, humid, highlands)	2300-3200m	900-1200	17.5/16-11.5	Barley and wheat
3.	Weiner Dega (Temperate, cool subhumid, highlands)	1500-2300	800-1200	20-17.5/16	Teff (most population lives here)
4.	Kolla (warm, semi-arid lowlands)	500-1500	200-800	27.5-20^{o}C	Sorghum, corn, teff-moist
5.	Bereha (hot and hyper-arid)	<500	<200	27.5	Pastoralism

[Source: MOA ,2000]

AEZ classification

The agro-ecological zone classification method is based on the growing periods, temperature and moisture regimes. Ethiopia is classified into 18 major AEZs subdivided further into 49 AEZs (Tsegaw, 2006; Deressa, 2010). The 49 sub AEZ are in turn grouped into six major categories according to MoA (2000) as listed below:

S/No	AEZ	Area(hectares)	%	Activity
1.	Per Humid	1million hectares	1	Suitable for perennial crops and forests
2.	Sub humid and humid	17.5 million 4.4 million	25 4	The most stable and ideal conditions for annual and perennial crops , forest, wildlife, and biodiversity
3.	Moist	28 million	25	Most important agricultural land for cereals –the dominant crops
4.	Sub-moist	22.2 million	19.7	Highly threatened by erosion
5.	Semi-arid	4 million	3.5	Less harsh
6.	Arid	53.5 million	31.5	Less productive and pastoral

2. Soils

19 soil types identified by MOA (2000), (FAO, 1984e; MOA, 2000 cited in FAO, 2006) and their distribution in the country.

Soils Type and Distribution in Ethiopia		
Soil type	**Area (km^2)**	**Percent**
Acrisol	55,726.5	5.0
Cambisol	124,038	11.1
Chernozems	814	0.07
Rendzinas	16,348	1.5
Gleysols	5,273.5	0.47
Phaeazems	32,551	2.9
Lithosol (Leptosols)	163,185	14.7
Fluvisols	88,261.5	7.9
Luvisols	64,063.5	5.8
Nitosols	150,089.5	13.5
Histosols	4,719.5	0.42
Arenosols	9,024	0.81
Regosols	133,596	12.0
Solonetz	495	0.04
Andosols	13,556	1.2
Vertisols	116,785	10.5
Xarosols	53,171	4.8
Yermosols	34,950	3.1
Solonchaks	47,217.5	4.2

[Source: MoA cited in FAO, 2006]

3. General features of the Agro-ecological Zones

Traditional zone	General features						
	Altitude (m)	**Rainfall (mm)**	**Soil type**	**Natural vegetation**	**Main plant species**	**Crops**	**Livestock**
High wurch (alpine)	> 3,700	> 1,400	Black, little disturbed	Afroalpine steppe meadow	Mountain grassland (*Artemisia*,*Helichrysum*,*Lobelia*)	None, Frost Limit	Sheep, cattle
Wet wurch (Sub-alpine)	3,700-3,200	> 1,400	Black, highly degraded	Subalpine	*Erica*,*Hypericum*	Barley (2 Crops/Year)	Sheep, cattle donkeys

Moist wurch (sub-alpine)	3,700-3,200	1,400-900	Black, degraded	Subalpine	*Erica*,*Hypericum*	Barley (1 Crop/Year)	Sheet, goats, cattle, poultry horses, bees
Wet dega (high land)	3,200-2,300	>1,400	Dark brown clay	Afromontane forest bamboo	*Juniperus*,*Hagenia*,*Podocarpus*,*Arundinaria*	Barley, Wheat, Neug, Pulses (2 Crops/Year)	Sheep, Cattle, Goats, horses, Bees, Poultry
Wet woyna dega (mid altitude)	2,300-1,500	> 1,400	Widespread drainage		*Acacia*,*Cordia*,*Ficus*,*Arundinaria*	Tef, Maize, Enset (In West) Neug, Barley	Cattle, goats, sheep, horses, mules, donkeys, bees, poultry
Moist woyna dega (mid altitude)	2,300-1,500	1,400-900	Red brown drainage		*Acacia*,*Cordia*, *Ficus*	Maize, Sorghum, Tef, Enset, (Rare) Wheat, Neug, Finger, Millet, Barley	Cattle, goats, sheep, horses, mules, donkeys, bees, poultry
Dry woyna dega (mid altitude)	2,300-1,500	<900	Light brown to yellow	Savanna	*Acacia*	Wheat, Tef, Maize (Rare)	Cattle, goats, donkeys, bees
Wet kola (low land)	1,500-500	>1,400	Red clay, oxidised		*Millettia*,*Cyathea*,*Albizia*	Mango, Taro, Sugar, Maize, Coffee, Orange	Cattle, goats, donkeys, bees
Moist kola (low land)	1,500-500	1,400-900	Yellow silt		*Acacia*,*Erythrina*,*Cordia*, *Ficus*	Sorghum, Teff(Rare), Neug, Finger, Millet, Groundnuts	Cattle, goats, bees, donkeys, poultry
Dry kola (low land)	1,500-500	<900	Yellow sand		*Acacia* spp.	Sorghum (Rare), Teff	Goats, cattle, camels, sheep, donkeys, poultry

Bereha (low land deserts)Note in the earlier table this unit is over 500 m!	<500	<900	Yellow sand	Acacia-Commiphora bush land	*Acacia,Commiphora*	Only With Irrigation	Camels, goats
Source: MoA /National Livestock Development Program, 1998, Ethiopia, Working Paper 4 - National Resources and the Environment							

4. Seasonal Calendar Developed by Women Group

Months in Ethiopian Calendar	Months in Normal Calendar		Activity
Meskerem	September	11	Chickpea planting, weeding of teff and sorghum, chat and coffee cultivation, families are short of cash, children start schooling, peak for malaria
Tikimt	October	11	Maize harvesting, bird scaring for sorghum, peak for malaria
Hidar	November	10	Sorghum and teff cutting, starting of hoe cultivation, malaria epidemic starts to recede
Tahisas	December	10	Threshing of most crops, hoe cultivation continues, ideal time for house maintenance orconstruction, wedding and manure transportation to the fields
Tir	January	9	Collection of sorghum stalks for land preparation, wedding continues, less agricultural work
Yekatit	February	8	Oxen cultivation starts, less agricultural work load
Megabit	March	10	Land preparation and sorghum planting, coffee and chat cultivation to help use belg rains
Miazia	April	9	Maize planting, haricot bean planting, sorghum and maize fields' cultivation for in-situ moisture harvesting before the end of the small rains
Ginbot	May	9	Plastering of houses, sorghum and maize cultivation, chat and coffee cultivation
Sene	June	8	Weeding and filling soil cracks to reduce evaporation and drying, food shortage at its peak
Hamle	July	8	Weeding, land preparation for teff, Haricot bean harvesting, wheat, barley, oats, horse bean,field pea and planting, malaria peak starts
Nehasse	August	7	Teff, noug, flax, fenugreek planting, moisture harvesting in chat and coffe fields before the dry season, land preparation for chickpea

[Source: Goal Ethiopia (2003)]

5. Ethiopia statistics for livestock numbers, meat and milk production and livestock exports and milk imports for the period 1995-2005

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Cattle nos (,000,000)	31.2	32.6	35.4	35.1	33.1	35.4	40.6	39.0	38.1	38.5
Sheep nos (,000,000)	12.0	12.5	13.4	12.2	11.0	11.4	14.3	15.0	16.6	17.0

Goats nos (,000,000)	8.4	8.4	10.5	9.5	8.6	9.6	9.6	9.6	9.6	9.6
Horse nos(,000,000)	1.20	1.22	1.23	1.21	1.14	1.25	1.48	1.45	1.45	1.5
Asses nos(,000,000)	3.20	3.15	3.17	3.10	3.06	3.41	3.90	3.80	3.77	3.80
Camel nos(,000)	370	410	479	527	262	327	475	470	468	470
Beef and veal prod. (,000 mt.)	267	270	274	290	294	304	352	338	331	336
Sheep meat prod. (,000 mt)	36.1	36.1	36.1	36.2	36.0	37.8	47.7	49.9	55.1	56.6
Goat meat prod. (,000 mt.)	25.0	25.0	28.0	27.1	25.6	28.6	28.7	28.7	28.7	28.7
Total milk prod. (,000 mt.)	996.0	1007.4	1019.1	1030.4	1365.5	1518.1	1676.4	1578.2	1582.3	1583.3
Cattle exports (head)	0	800	1218	549	326	44	544	2217	2000	n.r.
Sheep exports(,000 head)	4.0	4.0	15.5	30.7	40.0	15.0	1.1	11.7	0.053	n.r.
Goat & mutton meatexports(,000 mt)	0.5	1.8	2.5	1.9	1.2	0.2	1.1	3.6	2.1	n.r.
Milk equiv. imports (,000 mt)	11.8	11.8	14.0	12.9	8.3	3.8	12.7	21.4	5.6	n.r.

[Source:FAOSTAT, 2006; n.r.=no record]

6. Meteorological data from local weather stations

The Next tables are from weather stations in the area. The location of the weather stations can be seen in figure 2. All the tables describe the average rainfall per day and month, average monthly temperature, average monthly relative humidity, average monthly wind speed and average monthly evapotranspiration. As there are important variances in topography and climate over short distances, data sets of 3 stations in the zone have been given (Daro Lebu station, Hirna Station and Mieso Station).

Table 2 Meteorological data from Daro Lebu Station

Latitude: 8.117° **Longitude:** 40.733° **Elevation:** 1 434m

Month	**Prc.**	**Prc.**	**Prc.cv**	**Wet days**	**Tmp.mean**	**Tmp. max.**	**Tmp. min.**	**GrndFrost**	**Rel.hum.**	**Sunshine**	**Wind(2m)**	**ETo**	**ETo**
	mm/m	mm/d	%	days	°C	°C	°C	days	%	%	m/s	mm/m	mm/d
Jan	17	0.6	193.4	1.9	20.6	28.4	12.9	1.3	50.7	79.2	1.0	123	4.0

Feb	29	1.1	145.7	2.6	21.7	29.4	14.0	0.6	53.7	78.9	1.0	121	4.3
Mar	61	2.0	105.1	3.9	23.1	30.5	15.8	0.4	57.1	74.1	1.0	143	4.6
Apr	147	4.9	59.9	8.0	23.5	30.1	17.0	0.3	65.8	65.9	1.1	133	4.4
May	153	4.9	56.5	8.2	23.9	30.4	17.4	0.1	69.7	65.8	1.2	136	4.4
Jun	56	1.9	72.9	8.1	24.3	30.6	18.0	0.1	65.0	60.9	1.5	135	4.5
Jul	85	2.7	59.7	6.6	22.9	28.9	16.9	0.1	63.9	51.6	1.4	128	4.1
Aug	116	3.7	68.0	8.5	22.4	28.3	16.5	0.1	64.4	56.1	1.3	128	4.1
Sep	122	4.1	62.4	7.4	22.8	29.2	16.5	0.1	64.8	65.0	1.1	129	4.3
Oct	107	3.5	87.6	5.5	22.1	29.1	15.2	0.5	68.6	66.5	1.0	125	4.0
Nov	33	1.1	126.0	3.4	20.6	28.1	13.1	1.2	66.0	74.9	1.0	115	3.8
Dec	8	0.2	187.6	2.0	20.0	27.9	12.2	1.7	60.4	82.8	1.0	117	3.8
Total	934											1 532	

[Source: AQUASTAT 2011]

As the table illustrates, between April-May and Aug-Oct the area receive the most amount of rain, and receives 66.1 wet days in the year. The mean average temperature is 23.3°C and the reference evapotranspiration varies with the highest value in March (143mm) and lowest in Nov (115mm).

Table 3 Meteorological data from Hirna Staion

Latitude: 9.217° **Longitude:** 41.100° **Elevation:** 1 993m

Month	Prc.	Prc.	Prc.cv	Wet days	Tmp.mean	Tmp. max.	Tmp. min.	GrndFrost	Rel.hum.	Sunshine	Wind(2m)	ETo	ETo
	mm/m	mm/d	%	days	°C	°C	°C	days	%	%	m/s	mm/m	mm/d
Jan	23	0.7	185.6	2.3	17.0	24.9	9.1	3.6	56.1	77.1	1.2	111	3.6
Feb	41	1.5	139.1	3.0	18.2	25.9	10.5	2.4	58.2	75.9	1.3	111	4.0
Mar	72	2.3	93.5	4.3	19.7	27.2	12.3	2.0	60.5	71.7	1.3	133	4.3
Apr	126	4.2	57.6	7.8	20.4	27.0	13.8	1.2	67.7	64.8	1.4	125	4.2
May	118	3.8	55.8	8.7	21.2	28.0	14.4	0.7	70.9	65.1	1.5	130	4.2
Jun	60	2.0	71.9	9.1	21.8	28.4	15.3	0.4	65.4	61.0	1.8	132	4.4
Jul	161	5.2	43.8	7.4	20.3	26.4	14.2	0.3	64.5	51.3	1.7	124	4.0
Aug	209	6.7	38.5	9.7	19.8	25.8	13.8	0.3	65.3	55.0	1.6	124	4.0
Sep	130	4.3	51.9	8.4	19.9	26.3	13.6	0.5	65.6	64.2	1.4	123	4.1
Oct	62	2.0	111.5	5.6	18.8	26.3	11.4	1.5	69.2	67.8	1.3	119	3.8
Nov	24	0.8	160.1	3.3	17.1	25.0	9.2	3.1	68.5	75.5	1.3	107	3.6
Dec	8	0.2	215.9	2.3	16.4	24.5	8.3	4.1	64.3	81.3	1.3	107	3.5
Total	1 034											1 448	

[Source: AQUASTAT 2011]

During the months of April-May and July-Sept the area receive the most amount of rain, and receives 71.9 wet days in the year. The mean average temperature in this area is 19.2 °C and the reference evapotranspiration varies with the highest value in March (133mm) and lowest in Nov/Dec (107mm).

Table 4 Meteorological data from Mieso Station

Latitude: 9.233° **Longitude:** 40.750° **Elevation:** 2 033m

Month	Prc.	Prc.	Prc.cv	Wet days	Tmp.mean	Tmp. max.	Tmp. min.	GrndFrost	Rel.hum.	Sunshine	Wind(2m)	ETo	ETo
	mm/m	mm/d	%	days	°C	°C	°C	days	%	%	m/s	mm/m	mm/d
Jan	25	0.8	181.5	2.5	16.9	24.7	9.1	3.5	54.8	77.5	1.1	109	3.5
Feb	42	1.5	133.8	3.2	18.1	25.7	10.5	2.3	56.5	76.4	1.1	108	3.9
Mar	74	2.4	91.2	4.6	19.6	27.0	12.3	1.9	59.0	71.8	1.2	132	4.2
Apr	129	4.3	56.7	8.0	20.2	26.8	13.6	1.2	66.4	64.6	1.3	124	4.1
May	121	3.9	56.7	9.0	21.0	27.9	14.1	0.7	70.0	64.5	1.3	128	4.1
Jun	67	2.2	67.4	9.3	21.6	28.3	14.9	0.5	65.1	60.4	1.6	129	4.3
Jul	175	5.6	42.9	7.8	20.1	26.3	13.9	0.3	65.1	50.7	1.5	120	3.9
Aug	210	6.8	37.3	10.1	19.5	25.5	13.5	0.3	65.8	54.3	1.4	119	3.8
Sep	134	4.5	48.6	8.6	19.6	26.0	13.2	0.5	65.5	63.6	1.2	119	4.0
Oct	65	2.1	111.6	5.8	18.5	25.9	11.1	1.5	68.8	67.4	1.1	115	3.7
Nov	25	0.8	158.1	3.5	16.9	24.7	9.1	3.1	67.5	75.4	1.2	105	3.5
Dec	7	0.2	214.8	2.4	16.2	24.2	8.3	4.1	62.9	81.5	1.2	106	3.4
Total	1 074											1 415	

[Source: AQUASTAT 2011]

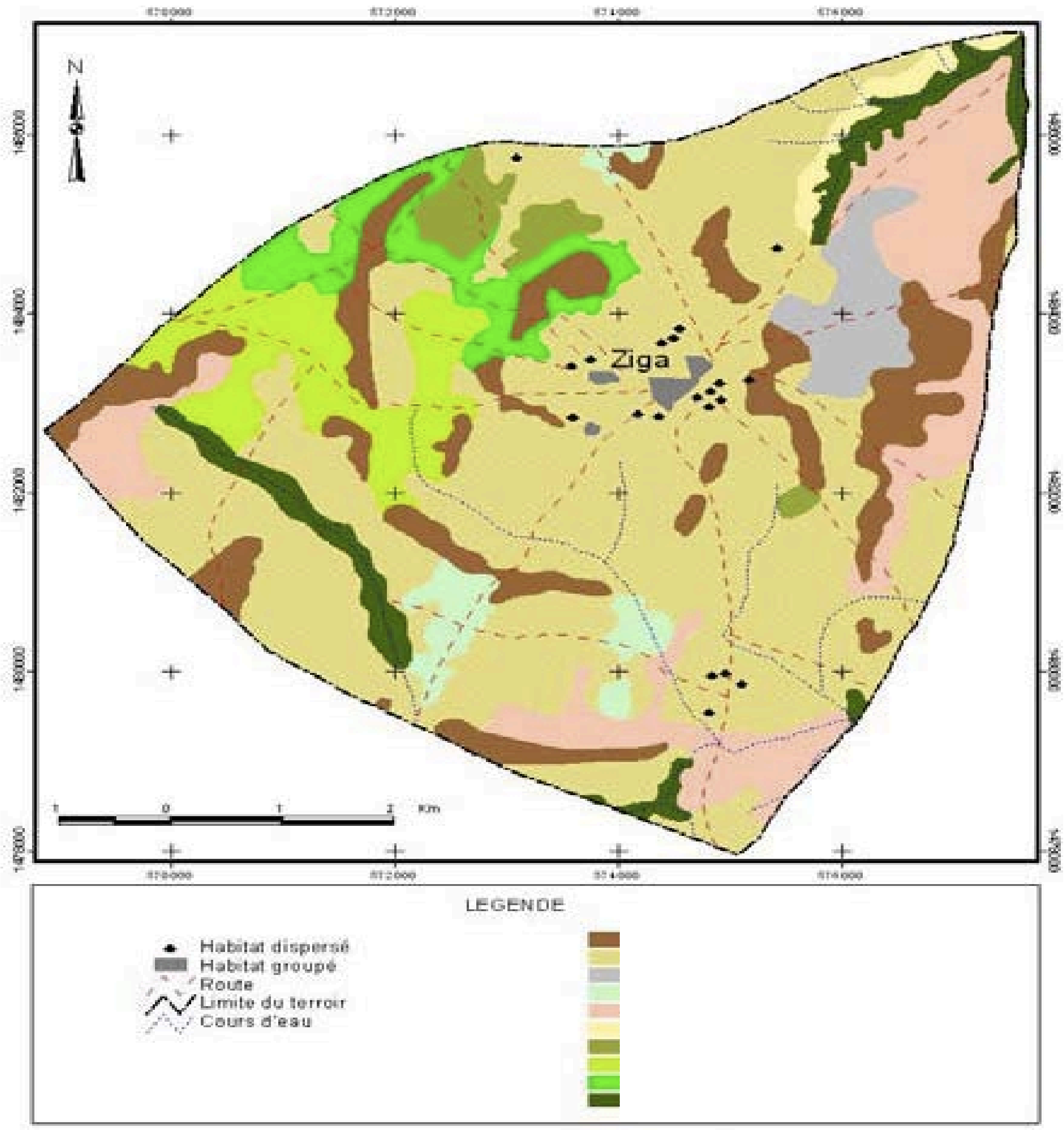
During the months of April-May and July-Sept the area receive the most amount of rain, and receives 74.8 wet days in the year. The mean average temperature in this area is about 19 °C and the reference evapotranspiration varies with the highest value in March (132mm) and lowest in Nov (105mm).

As the table have nicely demonstrated the rainy season is during the months of April-May and July-Sept (Aug-Oct (Daro Lebu)). The reference evapotranspiration increases as the precipitation value increases.

APPENDIX BURKINA FASO

1. Landuse maps of the two local study sites

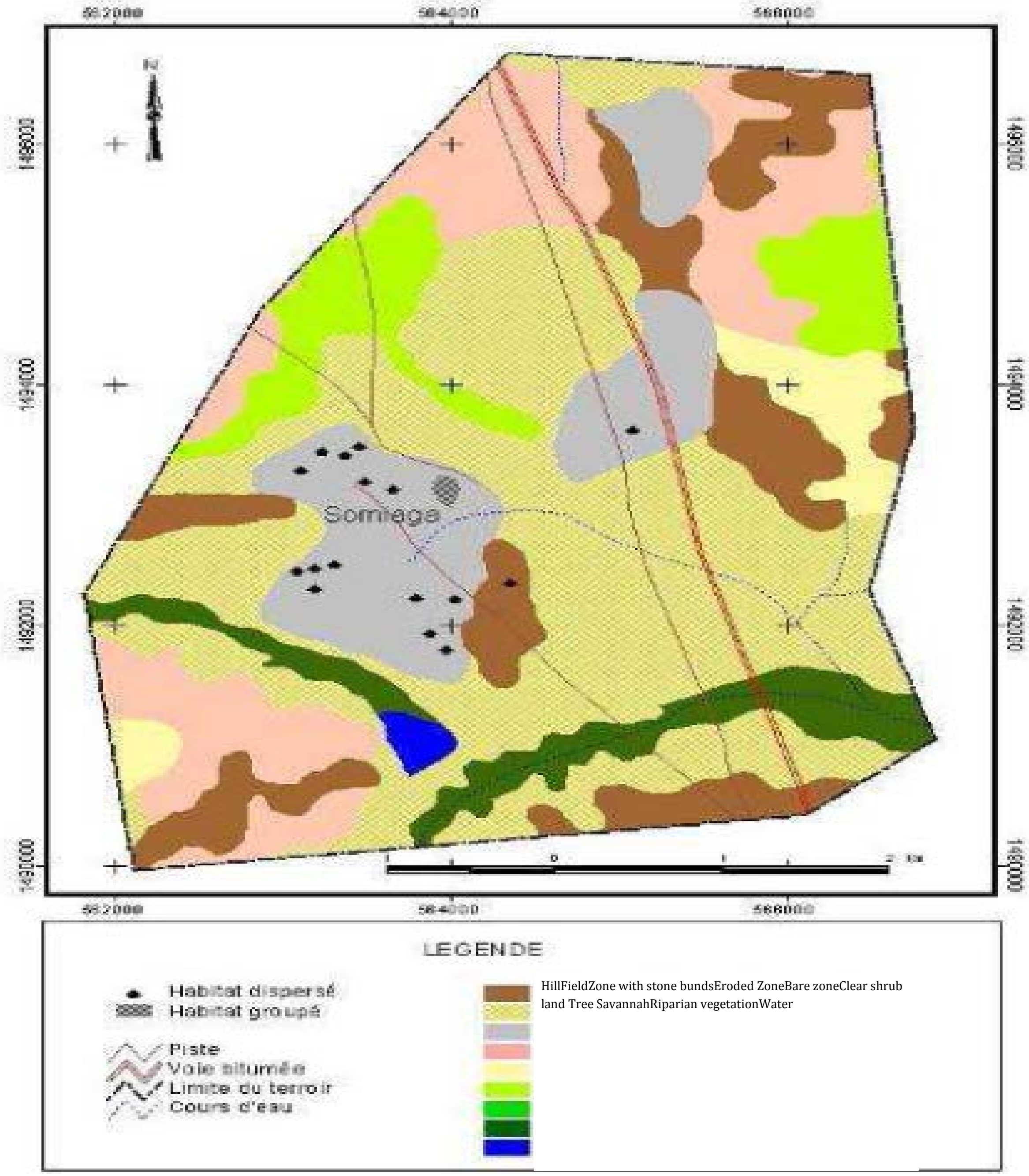
Figure 5 Land use map in 1996 of Ziga



[source: http://www.teledetection.net/upload/TELEDETECTION/pdf/20081008134105.pdf[2]]

Figure 6 Land use map in 1996 of Sogmaya

[2] The legende in the map has been translated from French to English



[source: WAHARA report[3]]

STAKEHOLDER ANALYSIS

The Main Stakeholders			
Stakeholders	**Interest**	**Power**	**Impact**

[3] The legende in the map has been translated from French to English

Meta Meta / WAHARA Research Institution	☐ Knowledge generation ☐ Job creation ☐ Image ☐ Research ☐ Networking ☐ Rural development ☐ Innovations	☐ Determine the goals and choices for the project ☐ Project management (selection of organizations to work with or not to work with, fund rising)	Determine the directions and focus of the project. For instance : spatial, technological and temporal directions.
Ourself (group B806)	☐ Learning experience, networking ☐ Knowledge ☐ Credits (9 ECTS) ☐ Recognition by the commissioner	☐ Creating multidisciplinary knowledge ☐ Information generation	Influence on choices of WHT selection
The Supporting Stakeholders			
Stakeholders	**Interest**	**Power**	**Impact**
Farmers and Households	☐ Food security ☐ Water security ☐ Increased crop ☐ Income	☐ The impact on the upscaling of the project (the power of feedback and choice) ☐ Local resources (labor, materials,local knowledge) ☐ Ownership ☐ Maintenance of the WHT	On the future direction of WHT
Community	☐ Food security ☐ Water security ☐ Increased crop ☐ Income ☐ Increased employment ☐ A kickoff to rural development	☐ Collective decision making ☐ Power of the mass ☐ Traditional knowledge/decision management ☐ Influence on collective actions.	Adoption/Rejection
Traditional Leaders	☐ Keep the privilege ☐ Image of the good leader ☐ Food security ☐ Gifts ☐ Rural development of the community ☐ Status	☐ Decision making ☐ Influence the public opinion ☐ Spatial distribution	☐ Adoption/Rejection ☐ Initial approval of the project ☐ Spatial distribution
Extension Workers	☐ Job security ☐ Learn new techniques ☐ Develop your own region (if local) ☐ Status	▪ Skills ▪ Facilitating ▪ Mediation (local languages) ▪ Local social network (connected to remote areas)	☐ Inclusion of hard to reach areas ☐ Support to the project staff, horizontal-vertical upscaling ☐ Gives feedback in behalf of the community/farmers

NGOs	☐ Donor funding ☐ Knowledge and dissemination of information ☐ Image (status) ☐ Solve the food/water crisis	☐ Political influence (the funding/investments are passing through the NGOs) ☐ Networking	☐ Spatial distribution ☐ Power to determine the overall outcome of the project ☐ Cooperation with the project ☐ Determine the pace of the project (slower/faster)
Donors	☐ Rural development ☐ Good relationships ☐ The image of the donor	☐ Political ☐ Financial control	Existence of the project
Governments	▪ Rural development ▪ Knowledge (new technologies) ▪ Image (good political image) ▪ Good relations with outside governments and international NGOs	☐ Selection of beneficiary communities ☐ Accepting partnering organizations ☐ Policy making ☐ Maintaining security and stability	☐ Facilitation ☐ Supporting ☐ Approval and implementation ☐ Knowledge generation by approving the project ☐ Service delivery through the key ministries