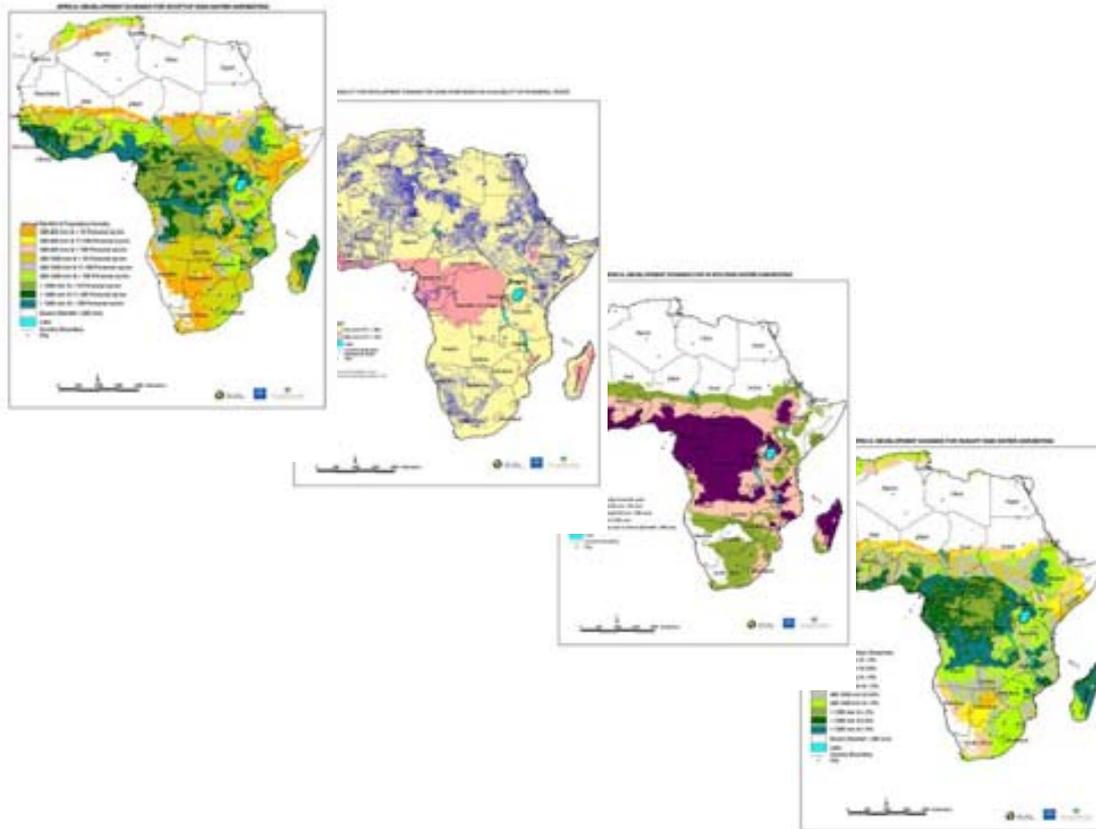


# Potential for Rainwater Harvesting in Africa: A GIS Overview

## Volume I



RELMA in ICRAF & UNEP

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## Executive Summary

Water is at the heart of Millennium Development Goals (MDGs) numbers 1, 3 and 7, and is indirectly associated with the success or otherwise of all the other Goals. But for Africa to meet the MDGs, bold and targeted actions will be required in the water sector. Given that about 300 million people in Africa, a third of the continent's population, are living under "water scarcity" situations, and urgent action is required else 12 more African countries will join "water scarce" nations by 2025. To address this, the African Water Vision for 2025 has set to develop the full potential of Africa's water resources for sustainable growth in the region's economic and social development, of which rainwater harvesting (RWH) and storage forms a major component. Among others, the Vision calls for "improving water wisdom", which is to be achieved by establishing an elaborate system of data collection, management, dissemination, including standardization and harmonization of data and information. Towards this end, data sources have been developed such as FAOSTAT, AQUASTAT and Agriculture towards 2015/30. However, continent-wide spatial information on rainwater harvesting potentials in Africa has been lacking. This information is necessary to raise world-wide awareness and guide policy decisions on the contribution of rainwater harvesting (RWH) towards meeting MDGs, the African Water Vision and generally, the water needs of men and women in Africa, for improved livelihoods and ecosystems.

This report describes the mapping by GIS (Geographic Information Systems), of the rainwater harvesting potential in Africa. The project provides an advocacy tool, which shows in spatial domains the expansive opportunities for RWH in Africa, and some ten selected countries; Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe. It produced a GIS database that captures the major factors associated with RWH (rainfall, topography, soils population density, land use). These baseline thematic maps were further combined through spatial analyses to produce composite maps that show attributes or "development domains" that serve as indicators of suitability for targeted RWH interventions, grouped as; (i) rooftop RWH, (ii) surface runoff from open surfaces with storage in pans/ponds, (iii) flood-flow harvesting from watercourses with storages in sand/subsurface dams and (iv) in-situ soil water storage systems. Consequently, the project produced a total of 73 maps, which comprise 29 thematic base maps, maps covering Africa and 44 composite thematic maps for the ten country case studies. All the maps are presented in Volume II. These maps provide a broad-brush, exploratory scale decision-support tool, since the GIS input data used was of low resolution, continental scales. Noting that the major ingredient in rainwater harvesting is rainfall, and guided by the fact that that if it rains, it can be harvested regardless of the quantities (too little or too much), the authors have therefore avoided labeling areas as either suitable or unsuitable for RWH. The decision of final prioritization is left to the user, after analyses of other factors beyond the GIS database, such as finances, cultural, political and local preferences.

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## List of Synonyms

ACZ	Agro-climatic zone
ADB	African Development Bank
AMCOW	African Ministerial Council on Water
AWTF	African Water Task Force
ASAL	Arid and Semi-Arid Lands
CAADP	Comprehensive Africa Agriculture Programme
ECA	Economic Commission for Africa
ET	Evapo-transpiration
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographical Information System
GPS	Geographic Positioning System
GWP	Global Water Partnership
GWP/AP	Global Water Partnership-Associated Programme
ICRAF	International Centre for Research in Agroforestry / World Agroforestry Centre
IWRM	Integrated Water Resource Management
MDG	Millennium Development Goals
NEPAD	New Partnership for Africa's Development
NGO	Non Governmental Organization
RELMA	Regional Land Management Unit
RWH	Rainwater Harvesting
SEARNET	Southern and Eastern Africa Rainwater harvesting Network
UNEP	United Nations Environmental Programme
WSSD	World Summit for Sustainable Development

## Introduction

At the World Summit for Sustainable Development (WSSD) in 2002, water and sanitation were recognized as inextricably linked to the eradication of poverty and to the achievement of sustainable development. Water was identified by the Secretary General as one of the five “WEHAB” specific areas (Water, Energy, Health, Agriculture and Biodiversity) in which concrete results are both essential and achievable. That water is required to address all of them need not be emphasized. The WSSD further reiterated the Millennium Development Goals (MDGs) target to halve by 2015, the proportion of people lacking safe drinking water and basic sanitation. Further deliberations on water have continued to dominate international forums, as at the Third World Water Forum in Kyoto, 2003, the International Conference on Water for the Poorest in Stavanger, Norway and the annual Stockholm Water meetings. The UN General Assembly in late 2003 adopted a resolution that proclaimed the period 2005-2015 as the International Decade for Action-Water for Life. The resolution emphasized that water is critical for sustainable development, including environmental integrity and eradication of poverty and hunger, and is indispensable for human health and well-being. However, estimates show that two out of every three people in the world will live in water-stressed areas by the year 2025, while the number of people without access to clean water on the continent will also increase from 100 million to 400 million. This is an uphill task which requires concerted effort to resolve, and should involve all stakeholders.

Within Africa, about one third of the population lacks safe drinking water, and it is estimated that 25 countries will be experiencing water by the year 2025. Africa has 3991 km<sup>3</sup>/year of renewable freshwater resources, yet the continent continues to suffer from water scarcity, a situation attributed to poor temporal and spatial distribution rather than absolute lack of water. To address this, there has been renewed focus on water issues in Africa, particularly through the African Ministerial Council on Water (AMCOW), the New Partnership for Africa’s Development (NEPAD), the Economic Commission for Africa (ECA), the African Water Task Force (AWTF) and partners such as the UN-Water, UNEP, UN-Habitat and the African Development Bank (ADB) among others. An important component towards meeting the African Water Vision is the need for managing rainwater resources for “drought proofing” communities subject to regular climatic variability and uncertainty. Rainwater harvesting and storage has been recognized as one way of achieving this. At the Pan-African Conference on Water in Addis Ababa, 2003, and at the African MDGs on Hunger meeting in 2004, rainwater harvesting was identified as among the important interventions necessary towards meeting the MDGs in Africa. Moreover, NEPAD’s, Comprehensive Africa Agriculture Programme (CAADP) recognizes land and water management as one of three “pillars” that can make the earliest difference to Africa’s agricultural crises. In total, 874 million hectares of land in Africa could benefit from increased agricultural production by increasing the managed use of water, which also includes rainwater harvesting and storage. Given that 40 billion working hours are lost each year in Africa carrying water, causing “water poverty” which affects mostly women, this can be reversed by supplying water close to home. In areas with dispersed populations and where the costs of developing surface or groundwater resources are high, rainwater harvesting and storage have proved a more affordable and sustainable intervention. However,

despite its proven uses for domestic, agricultural, commercial and environmental purposes, rainwater has not been fully utilized in Africa.

## **Why Focus on Rainwater Harvesting**

Rainwater harvesting is the deliberate collection of rainwater from a surface known as catchment and its storage in physical structures or within the soil profile. Rainwater may be harvested from roofs, ground surfaces as well as from ephemeral watercourses. Rainwater can also provide affordable water for household use, agriculture, environmental flows and prevention of flood damage. Various technologies to harvest rainwater have been in use for millennia and new ones are being developed all the time. They include macro-catchment technologies that handle large runoff flows diverted from surfaces such as roads, hillsides, pastures, as well as micro-catchment technologies that collect runoff close to the growing crop and replenish the soil moisture. Rooftop harvesting structures have the advantage to collect relatively clean water, while weirs and dams on ephemeral watercourses can store relatively larger volumes and for longer periods.

For years, NGOs, faith-based groups and networks have been advocating the use of rainwater harvesting with slow progress. One of the problems has been lack of tangible scientifically verified information which can be used to demonstrate the areas where rainwater harvesting can be applied. The need for information in user-friendly formats and which is easy to update, query, manage and utilize, has popularized the use of Geographic Information systems (GIS).

## **Responding to Demands for Thematic Geo-Spatial Data in Africa**

Map of rainfall, topography, population and other spatial characteristics are easily available for Africa e.g. from FAO, SOTER, ILRI databases. But to turn these maps into "information" requires further data analyses and processing for specified needs, ultimately creating "thematic data". The source of data to do this is as important as the application of relevant methodologies. There are many ways to acquire data for creating GIS databases. They range from cartographic surveys, GPS (geo-positioning system) mapping using portable GPS units, satellite remote sensing, and use of existing published data. It may also include mapping factors associated with rainwater harvesting, such as land use/cover, roof surface areas, climatic variables and relating these to water harvesting. One of the more popular methods used at global scales utilizes freely available satellite data, such as NOAA-AVHRR, Landsat (free for Africans), TERRA-MODIS, or purchased products, such as SPOT, CEOs. But use of remote sensing is suited to localized studies and may not be applicable to continent-wide mapping. An alternative is to use FAO's global databases. The FAO has collated data on various aspects of water, food and agriculture, including irrigation, but even these do not capture the potential for RWH in a manner that can be used for awareness creation and development planning. With the advent of satellite technology, hydrological and meteorological thematic data are generated daily, sometimes at very high resolutions, including coverages for Africa. However, due to the need for processing, even these highly technological databases are still too raw for guiding policy maker as to where investments in RWH would be most appropriate. This is because there are many other factors associated with rainwater harvesting, and these must be factored in the GIS to make it relevant. It is for this

reason that this GIS database was developed to meet the demands of spatially-relevant tools for advocacy and decision support.

## **Project Scope**

UNEP and ICRAF are members of the Rainwater Partnership whose objective is to promote the use of rainwater by mainstreaming the resource into Integrated Water Resource Management (IWRM). To meet the growing demand for broad scale spatial data on rainwater harvesting in Africa, UNEP and ICRAF embarked on a project to develop GIS thematic data of the potential for RWH in Africa in spatial domains. Developed for continental and country scales, it offers broad-brush development domains associated with rainwater harvesting potentials for Africa, and some ten selected countries; Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe. As the major ingredient in rainwater harvesting is rainfall, and knowing that if it rains, it can be harvested regardless of the quantities (too little or too much), the database does not label any areas as either suitable or unsuitable for RWH. The final prioritization should be made after more detailed analyses that should include other factors beyond the GIS database, such as finances, cultural, political and local conditions. The GIS database developed here is for awareness creation at international forums to illustrate the potential contribution of RWH in meeting MDGs 1, 3 and 7, and for decision support targeting decision makers, donors and governments working with rainwater harvesting projects.

## **Project Objectives**

The main objective of this project is to demonstrate in spatial domains, the huge potential for rainwater harvesting in Africa, and thereby provide a tool for advocacy and decision support, for RWH in Africa and some selected African countries.

## **Specific Objectives**

Development of GIS database of rainwater harvesting potential in Africa, for selected rainwater harvesting technologies (rooftop RWH, surface runoff into ponds/pans, sand/subsurface dams and in-situ RWH)

Provide country level GIS databases showing development domains of rainwater harvesting potential for Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe, for the same RWH interventions.

## **Developing the GIS database**

The GIS database of RWH potential for Africa was developed by a multi-disciplinary team of hydrologists, engineers, socio-economists and GIS experts, with regular peer reviews by selected professionals from participating countries. The general methodology comprised the following components:

Consultative meetings & decision on what to map

Identifying mappable RWH technologies

Developing the criteria for mapping attributes

Creating the GIS database

### **Consultative Meetings & Decision on What to Map**

All through the project, regular consultative meetings and peer reviews were held. The meetings were used to agree on the criteria for mapping the RWH potential, for evaluation and monitoring of the progress, quality control and for guidance. By considering the scales of input data available, the original idea to produce maps with legends that show priorities as high, medium or low for rainwater harvesting was changed in favour of maps that show “development domains”, comprising combinations of mapping attributes that affect RWH, such as rainfall amount, population density, land use and/or slope. Moreover, other un-mappable factors are necessary in the final prioritization of RWH and depending on local conditions, RWH may be a priority even given high rainfall, low population or other variables. Peer reviewers included persons not directly involved in the project, so as to gain some external critique.

### **Identifying Mappable RWH Technologies**

One of the first tasks was to decide which rainwater harvesting technologies can be mapped at continental and country scales, given that RWH is a site specific activity. To begin with, digital GIS data were gathered from laboratories (particularly ILRI and ICRAF), and non-spatial data from libraries, local and international organizations, individuals and the internet. Contacts were also made with relevant ministries in the selected countries. In addition, data were collected on factors associated with RWH, the critical values for climatic, topographic and other variables that influence RWH, and the types of technologies most commonly practiced in Africa and/or those which are applicable (Annex 1). This resulted in a long list of commonly adaptable RWH technologies, but those to be mapped in the project were broadly grouped as:

- Rooftop RWH and storages into above or below ground storage tanks
- Surface runoff collection from open areas and storage in ground-based structures e.g. waterpans, ponds, underground tanks
- Flood runoff harvesting from watercourses (ephemeral streams) and storage in sand/subsurface dams (this includes also possibility of weirs, small earthen dams and on-stream ponds)
- RWH water collection and storage in-situ in soil profile (green water) for crop production.

It was not possible to map other methods of water harvesting such as road runoff harvesting, rock catchments due to the low resolution of data available. For each of

these RWH interventions, the critical values for mapping used (Table 1) and criteria for mapping specific RWH interventions were derived as follows.

### **Rooftop rainwater harvesting**

Rooftop RWH is one of the easiest ways of providing drinking water at household level. For instance, for rural households in Africa, in terms of rainfall availability for roof water harvesting, an area receiving just 200 mm annual rainfall has as much potential (and higher priorities) as one receiving 2,000 mm. For example, simple arithmetic assuming per capita rural water consumption at 20 litres/day shows an annual water demand of 7.3 m<sup>3</sup> per person/year, which could be supplied by a roof catchment of 36.5 m<sup>2</sup>, if only 200 mm of rainfall per annum were available. Therefore all that is required is the presence of roofs to provide the necessary catchments. In countries where settlements have been mapped such as Kenya, it is possible to show where rooftop RWH can be targeted. By applying mapping masks (a mask hides unwanted information, e.g. settlements having piped water), it is possible to prioritize where rooftop RWH would be most opportune. In countries spatial lacking data on settlements, it was assumed that all areas have a potential for rooftop RWH as long as annual rainfall is at least 200 mm. High rainfall areas do not necessarily preclude the need for rooftop RWH because of poor levels of development, and neither do low population areas, where scattered settlements may mean centralized piped systems are uneconomically viable.

### **Surface runoff collection from open surfaces into pans/ponds**

The potential of RWH and storage in small ponds and pans refers to collection of runoff from open surfaces, such as roads, home compounds, hillsides, open pasture lands and may also include runoff from watercourses and gullies. Therefore this is an intervention that could be implemented almost anywhere, so long as local site conditions are permit. For the GIS mapping, only areas with steep slopes (> 8%) and areas with very low rainfall (< 200 mm) were removed. In general, runoff harvesting into ponds depends also on soil type and geology, especially to avoid seepage problems. As there was no continent-wide spatial data showing the relevant soil properties, e.g. low permeability, the aspect of soil types could not be incorporated in the GIS analyses, and therefore the maps obtained are rather too inclusive. Since seepage can be controlled in water pans/pond through different interventions, and this fact should be acknowledged in using the maps.

### **Flood flow storages and sand/sub-surface dams**

The potential of sand/subsurface dams in an area is a function of the availability of sand rivers, topography that allows construction of weirs, geology to suit storage structures and the presence of a population to make use of the water. Sand and sub-surface dams are small-sized RWH structures, whose location in ephemeral sand-river beds demands detailed surveys, preferably with thorough ground truth. Ideally, there is no realistic way to show the suitability of their location in low resolution GIS databases but since this database is for awareness creation, it is possible to show that sand/subsurface could be applicable along various watercourses on a map, by removing those water-courses and land units where the intervention may not be applicable. Moreover, most sand rivers tend to be in ASAL areas where population density is very low. Site selection is based on availability of settlements rather than

population density. Thus, in this database, the potential for sand/subsurface dams was shown by a combination of Rainfall/ET index (<60%) and presence of ephemeral rivers. It was noted that much smaller streams did not show on the database due to scale limitations. This mapping also generally depicts the potential for flood runoff harvesting from watercourses by any other type of storage, including weirs, small earthen dams and ponds in the dry areas.

At the Africa scales, data were available for ephemeral rivers for some of the countries, although it does not distinguish which ones may be sand rivers. At country scale, the maps for Kenya and Tanzania when queried were found to represent sand rivers relatively well on removing humid areas. However, for Ethiopia, some of the ephemeral rivers lie above 2000 m.a.s.l, and may not be sand rivers. It was not possible to use soil maps to identify "sandy soils" as suitable catchments, and therefore areas likely to host sand dams as this was found to be unreliable. This is because the sand in a sand-river is the product of a long journey along the river profile and may not necessarily come from the surrounding land. The idea to use sub-basins to identify areas suitable for sand dams had been suggested by some members of the team. However, it should be noted that sub-basins simply comprise smaller basins containing the full lengths of rivers that drain to a major river. Many sub-basins emanate from the head-waters, usually at mountain water towers, and therefore, a sub-basin would include from top to bottom of a given river/stream, including areas where river profile does not contain sand. Consequently, use of sub-basins would inadvertently introduce errors and was abandoned, in favour of the rainfall/ET index to delineate ASAL areas.

### In-situ water harvesting

In-situ RWH refers to all activities in which rain water is harvested and stored within the soil profile for crop production. It may include open-sky RWH systems such as terraces, pitting methods such as zai, bunding methods such as majaluba and large external catchment systems such as trapezoidal bunds. Since water is stored in the soil, the main criteria for mapping is that the area may be in need to soil moisture replenishment, at some point within the year. After lengthy deliberations with peer reviewers, it was agreed that wet areas could still benefit from in-situ RWH due to climatic variability. Thus, areas with annual rainfall in the range 200-1200 mm rainfall were considered in need of in-situ RWH. By removing protected areas and areas with saline soils, it was assumed that the rest of the land had agricultural potential and was therefore eligible for in-situ RWH as there was no reliable data showing agricultural areas for all of Africa. Topography was considered a non issue, since it can be altered by terracing or bunding. This means that large areas in Africa can adapt in-situ RWH.

**Table 1 Types of Rainwater Harvesting Interventions and Input Spatial data**

RWH system	Criteria	Classes	Reference
Rooftop tanks	Presence of settlements Rainfall in sufficient amount >200mm &	Rainfall Desert 0 - 200 mm Low – 200-400 Medium 400-1200 High > 1200mm	FAO, 2002, TERRASTAT  FAO 1987

	Population density >10/km <sup>2</sup>	Population Low - < 10 Medium 11-100 High > 100	Gridded Population of the World 1999- 2000
Ponds and pans	Rainfall > 200 mm  Slope <2%  May include areas with low population for livestock/wildlife	Rainfall Desert 0 - 200 mm Low – 200-400 Medium 400-1200 High > 1200mm  Flat :Slope < 2% Undulating 2-8% Steep > 8 %	FAO, 2002, TERRASTAT
Sand/subsurface dams	Require ephemeral sand-river bed  Suited to drylands	Ephemeral rivers  Drylands P/ET < 60 Wet areas P/ET > 60%	Hoogeveen 2000 FAO 1983 Sombroek et al, 1982
5. In-situ systems (all types of on- farm systems; macro & micro catchments)	Agricultural lands Rainfall	Agric lands- Yes Other land – No Rainfall Desert - 0-200 Low 200-750 Medium 750-1200 mm High >1200	Global Land Cover & FAO, WB 2001  FAO, 2003. Africover project  Hai, 1998
6. Underground tanks	Not to be mapped	Not mapable at country scale	
7. Rock catchments	Not to be mapped	Not mapable at country scale	
8. Small dams & weirs	Not to be mapped	Lack of good resolution data	

## Developing Criteria for Mapping Attributes

The GIS database of RWH potential in Africa was developed using ArcGIS and Arcview software, by utilizing both vector and raster (gridded) available databases. The major variables identified for prioritizing RWH in the GIS were rainfall, topography, soils, land use and population density. In general the database comprises baseline thematic maps and composite processed maps, developed using mapping criteria as follows:

### Rainfall data

Rainfall is the main ingredient in RWH. Ideally, seasonal rainfall would have been more useful but due to the heterogeneity of the continent, available continent-wide spatial data was on mean annual rainfall, which was utilized. In terms of classification, annual rainfall below 200 mm shows deserts with low population and high risks of production. Due to the need to target areas where there is huge incremental benefit in RWH, areas receiving 400-1200 mm are considered most

optimal. Above 1200 mm, RWH for crop production is not a necessity except for drinking water.

### **Rainfall/ET index**

Agro-climatic zone (ACZ) maps give an indication of the inherent risks to rainfed crop production and therefore provide some basis for setting criteria for mapping in-situ RWH systems, sand dams, and even pans/ponds. This is because ACZ maps have been created by combining important climatic variables (rainfall, relief, temperatures). However, this database could not obtain reliable ACZ maps for Africa except for some of the countries and only ET digital data were available for Africa scale. Thus Rainfall/ET were calculated and used. By setting Rainfall/ET of 60% as threshold for wet areas, this index was used in delineating areas considered too wet to contain sand rivers, and hence used in delineating areas suitable for sand/sub-surface dams.

### **Land slope**

The slope of land is important in site selection and implementation of all ground-based RWH systems, especially ponds, pans, weirs and in-situ RWH. Due to the need for continent-wide and country scales of the mapping, 90-m resolution digital elevation models (DEMs) obtained from SRTM were used. Slope steepness was also determined in GIS analyses and used for showing areas preferable for runoff harvesting from open areas.

### **Population density**

Africa-wide digital data on population were obtained from FAOSTAT (resolution 5 km), and a classification scheme was developed that allowed a minimum of one household per sq. km as the minimum population density for RWH. This decision was arrived at after several trials with higher values. It was noted that the nature of population density in Africa is such that with the exception of mining and urban areas, population in the rural areas is concentrated in the wetter, better agriculturally endowed areas in most countries. Wet areas are also likely to be well served with basic infrastructure, including piped water, and irrigation schemes. On the contrary, it is the drier areas, where perennial rivers are scarce and far between, ground water is usually expensive or difficult to exploit (usually saline too), and where the most viable source of water becomes RWH, but where population density is sometimes lowest. The nature of ASALs is such that settlements are scattered, each holding only a small population and therefore, supply of piped water can be uneconomical and difficult- the very reason RWH becomes the most viable alternative. ASALs also hold large numbers of livestock that require watering, and this may not be evident from the human population statistics. There are limitations in using population density to prioritize areas for RWH interventions because the areas with the lowest population (ideally the lowest priority) tend to be the most disadvantaged and where RWH would have the greatest impact.

### **Land use/cover**

It was not possible to get full coverage at good resolution for land use/cover for full Africa coverage, but Africover data were available for some of the countries. Land use/cover maps were used for delineating agricultural areas and those areas used for special purposes, e.g. forests. This layer was used in developing domains for in-situ RWH. Africover data was used for individual country maps.

## Ephemeral streams

The coverage on ephemeral streams was used for mapping sand/sub-surface dams. Ephemeral streams can range in size from small streams not captured in country-scale maps to large valleys. For GIS mapping, it would require high resolution data, e.g. from satellite imagery such as Quickbird, SPOT or Landsat TM, which are capable of showing sand in sand-rivers in dry areas. Lacking this level of resolution, this study adopted available thematic data on ephemeral streams (1:5 million). However, the low resolution of these data means that most small ephemeral streams are not depicted. However, as a broad-brush overview, this layer provided a relatively good representation of areas that could benefit from sand dams. The available DEM of 90 m resolution was too coarse for this project since it weeded out large areas known to be suitable for sand dams when a 2% slope was used as the lower limit. It and thus slope classification was abandoned.

**Table 2 Characteristics of input data for GIS mapping of RWH potential in Africa**

Item	Criteria				Reference
Mean annual Rainfall	RWH for crops is practiced under mean annual rainfall= 150 mm (max 300, min 50 mm)				Oweis et al, 2001
	Shallow soil depth <50 cm				
	Low slope < 4%				
Population	Population density ranges 10-60 per km <sup>2</sup> In India it is 200 persons/km <sup>2</sup>				FAO 1987
	WH using negarims has been done in areas with 200-250 mm rain				
Rainfall	Low RWH priority for 200-400 & high>1200 mm High RWH priority medium rainfall 400-1200mm				FAO, 2002, TERRASTAT
Topography	FAO classification: 0-2% Flat; 2-8% Undulating; 8-16% Rolling; 16-30% Hilly; > 30% Mountainous				FAO, 2002, TERRASTAT
Tropics Length of Growing period (LGP)	Growing Period (days) 75-119 – Semi arid zone 120-269 – Savanna Zone 270-365 Rainforest zone				FAO 1983
Maize crop	Minimum rainfall 300-400 (<300)				FAO 1983  Sombroek et al, 1982
	Relative ET deficit should not be < 0.4 (same as the 60% we adopted for P/ET)				
	Salinity : EC should not > 8 ms/cm Alkalinity ESP should not > 35% pH >4.5, (Best suited pH 5.5-7.0)				
Crop water requirements for	Maize – 500-800 Sorghum/millet-450-650 Soybean 450-750				Critchley and Siegert, 1991
Growing periods of some crops	Maize 80-180 days Sorghum 120-130 days Millet, 105- 160 days Beans 75-110 days				
Growing periods & Rainfall requirements	Millet -70 days	Millet -250-450 mm		Jaetzold and Schmidt, 1983  Hai, 1998	
	Sorghum – 75 Groundnuts – 50 Katumani maize – 85 Dryland maize – 75 Beans – 70 Cowpeas – 60	Sorghum – 200-500 Groundnuts – 180-550 Katumani maize 260-450 Beans – 230-450 Cowpeas – 180-320 Cassava – 500-1000			
Domestic water demands – Daily consumption (litres) for rainfall different zones					
User	High	Medium	Low	Unclassified	
Human	20	15	10		Barnes et al, 1983
Dairy cattle	50	50	50		

Local cattle	17	17	17	Ministry of Water Development 1992
Sheep/goats	4	4	4	

## Creating the GIS Database

This meant putting together all the different files and creating thematic maps. This was done by GIS experts in close consultation with the other team members. Ideally, hydrological models (Patched Thirst, SWAT, Runoff Curve Numbers) should be used to show RWH potential, but most of them are applicable at catchment scales and require a lot of detailed data and time input. Thus, this project utilized ArcGIS and Arcview tools to retrieve global databases and reclassify them using classification templates relevant for RWH (Table 2). This produced the baseline thematic maps such as rainfall, population and soils. The next stage was to use agreed criteria to eliminate those areas where RWH is not applicable or is unlikely to make an impact for a specified technology. This exercise used map analyses tools and calculations in the GIS, by combining two or more baseline maps (Table 1). For instance for sand/subsurface dams, this entailed showing areas where rainfall is at least greater than 200 mm and the Rainfall/ET index is less than 60%. The legend of the composite map obtained was described in terms of the major characteristics represented on the map, so as to leave the user free to decide which combination of attributes is most relevant for a given RWH intervention and socio-economic conditions. The GIS database developed has been retained as inter-active files. The maps have also been converted into JPEG formats to enable non-GIS users access them in ordinary MS Office software. Posters for awareness creation were also made using the database.

## Major constraints faced

One of the main constraints faced in the continent-wide mapping of RWH potential in Africa was lack of high resolution input data, as most available data were of scales 1:5,000,000, which is too small for most of the factors associated with RWH. It is for this reason that some RWH interventions such as rock catchments and underground tanks were not mapped. In addition, although thematic data on drainage basins was available, it was not used in the mapping exercise because of the difficulty of making it relevant at continent scales, e.g. compare the Congo Basin and the Ewaso Ng'iro Basin. Another limitation was the soil map. Although soil factors are important in site selection for ground-based RWH systems, the available soil maps were either not covering the whole continent (e.g. SOTER database), but the FAO Soils of the World map, which was used, was of low resolution. The available file on ephemeral rivers did not cover some countries and due to scale, seemed to underestimate the potential for sand dams. Furthermore, the resolution of the data might differ between layers. Thus, this is a low resolution database developed for mapping RWH interventions which are in nature quite site specific e.g. sand dams, in-situ systems, pans and ponds. The database has its limitations, and only development domains may be shown. This GIS database therefore should be used without querying detail because it was not created for that purpose.

## **GIS Database on Potential for Rainwater Harvesting in Africa**

### **Available formats of the GIS database**

As a GIS project, the products of this work are best viewed and accessed in soft formats in an interactive GIS environment, where the reader can zoom in, overlay other factors and query the database for specific questions. These products are available at the GIS laboratory at ICRAF, and on CD-ROMs, which can be obtained on request from ICRAF. For general circulation, the data has been converted into ESP, pdf and JPEG formats and can therefore be loaded onto any computer and viewed using MS office software. In addition, posters have been produced for display at meetings, conferences and for awareness creation. Bulletins will soon be developed and this report also contains in and second volume the full range of all the GIS products developed, in hard copy A-4 formats.

### **Contents of the GIS Database**

The spatial mapping of RWH potential in Africa produced three sets of map products covering Africa and some ten selected countries; Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe. It contains baseline thematic maps which capture the major bio-physical factors associated with rainwater harvesting (rainfall, topography, soils) and socio-economic prevailing conditions (population density, land use, protected areas). The main outputs comprise a set of reclassified composite maps of the major development domains relevant to each of the four RWH interventions identified, i.e. (i) rooftop RWH, (ii) surface runoff from open surfaces with storage in pans/ponds, (iii) flood-flow harvesting from watercourses with storages in sand/subsurface dams, and (iv) in-situ soil water storage systems.

A total of 73 of maps were developed in the project. These include 29 thematic maps showing rainwater harvesting potential in Africa and 44 composite maps for the ten country case studies. These maps are presented in Volume II. Due to the scale constraints, this GIS database provides a broad-brush, exploratory scale knowledge base, which can be used for awareness creation and general guidance on where to invest in RWH. Since the major ingredient in rainwater harvesting is rainfall, and based on the fact that if it rains, it can be harvested regardless of the quantities (too little or too much), the authors therefore avoided labeling any areas as either suitable or unsuitable for RWH. Going to the details of the suitability of areas for RWH requires more detailed information, higher resolution input data, including hydrological models, and consideration of other factors beyond the GIS database, such as finances, cultural, political and local preferences. The user must be aware of this.

### **GIS database for Africa**

All the 29 maps showing RWH potential in Africa can be summarized through five thematic maps covering Africa, showing the development domains for rainwater

harvesting based on rooftop RWH, surface runoff into pans/ponds, sand/subsurface dams and in-situ RWH. In terms of extent, rooftop RWH covers the largest areas, because it is potentially possible to harness rain water at home in all rural and urban settlements. However, lack of spatial data on which settlements already have other forms of water supply, e.g. piped water, means that these were not weeded out and users of the database must be made aware of this. Surface runoff harvesting is a site specific intervention and therefore potentially possible almost anywhere so long as it rains. In that case, the map shows that all areas receiving more than 200 mm have the potential for runoff harvesting, albeit the necessity for the intervention reduces as rainfall increases. One interesting observation is that the areas predicted as suitable for sand/subsurface dams are also the driest. For in-situ RWH, the need to be inclusive meant that even relatively wet areas, such as the Congo basin, have been retained as potentially useful for green water harvesting, but the priority increases for conservation increases as the water deficit increases.

Africa's semi-humid and semi-arid areas suffer erratic and highly variable rainfall interspersed with long dry spells for which conventional water sources become inadequate. Thus, rainwater harvesting offers great scope for improving water supply, especially to communities in isolated settlements, and also for drought-proofing crop production. Generally, the FAO has recommended medium rainfall areas for the development of rainwater harvesting technologies, albeit lower rainfall areas are more critical, by consideration of the greater vulnerability of these areas. Higher rainfall areas sometimes also require RWH due to costs associated with centralized large schemes, which are unaffordable in some countries and communities.

### **Country-Specific GIS Databases**

Country scale GIS databases were made to identify more clearly areas having good RWH potential for specified technologies. Wherever possible, country scale GIS input data were used but when not available, global databases were used. Rainwater harvesting is a hydrological intervention which these days is best depicted through hydrological models, capable of showing directions of flow, runoff and run-on areas and even best location for impounding structures. But due to scale, such level of detail has not been provided in this work. The general observations for country GIS databases as are follows:

#### **Botswana**

Botswana is generally an arid and semi-arid country, having few surface water resources, a generally flat to undulating topography and a low human population density. These form a combination of factors that favour RWH as the intervention to reach especially scattered small settlements. The entire country receives less than 1200 mm of rainfall making RWH a necessity. Due to lack of land use data, in-situ RWH was not mapped.

#### **Ethiopia**

Ethiopia is a heterogeneous country with sharp gradients in rainfall, topography, population density, land uses and soils. Development domains for RWH therefore vary accordingly. However, the need for RWH has been expressed almost for the whole country and it was not easy to delineate areas more needy than others. For

instance rooftop and runoff RWH is potentially applicable throughout the country, while in-situ RWH is applicable in most of the country.

### **Kenya**

Kenya is a relatively dry country with population concentrated around the wetter central highlands and the Rift Valley. Development domains for RWH in Kenya reveal the same pattern, especially for roof top and runoff harvesting. Sand dams are predicted to be potentially applicable in the dry areas while due to land use patterns, in-situ RWH is predicted to be applicable to the central areas.

### **Malawi**

Malawi is a relatively wet country, although medium rainfall range (400-1200) covers the largest area. It has a high population density which means that rooftop RWH is applicable throughout the country. Due to lack of a streams file, sand dams were not mapped, but the country has great scope for in-situ RWH.

### **Mozambique**

Mozambique has variable climate and topography, albeit relatively well endowed with rainfall since no area receives less than 400 mm. The spatial distribution of the settlements indicates that rooftop RWH is required throughout the country. Due to lack of a streams file, sand dams were not mapped but in-situ RWH is applicable over large areas.

### **Rwanda**

It was not easy to map Rwanda because of lack of country-scale data and only the available global databases were used. Rwanda is an equatorial country with high rainfall, high population densities and steep slopes. Due to socio-economic reasons, rooftop RWH is necessary in Rwanda as the rural areas do not have piped water systems. Sand dams may not be a priority in Rwanda but runoff harvesting is feasible, especially in the drier south western areas.

### **Tanzania**

Tanzania is one country where runoff and in-situ RWH have been widely adopted, and therefore it provided a good testing case for the reliability of the database. Tanzania has large areas having medium rainfall, well distributed population and gently undulating topography suited to RWH. The maps obtained show that all types of RWH are potentially applicable throughout most of the country with the exception of protected areas and high altitude mountains.

### **Uganda**

Uganda combines high rainfall with high population and large areas prone to wetland conditions, yet RWH is an important source of water due to poor state of development of centralized systems. In addition, the "cattle corridor" comprising north eastern to western Uganda is a relatively dry zone where RWH is necessary even for crop production. Thus, most of the country could benefit from roof runoff harvesting, while about half of the area requires runoff and in-situ RWH.

### **Zambia**

Zambia offers a relatively homogenous topography, land use and rainfall patterns. The entire country does not have arid region (rainfall < 400 mm) and all types of RWH have great potential in Zambia especially in the central and southern regions. With

the exception of protected areas, settlements are scattered throughout the country offering great potential for rooftop RWH. Sand/subsurface dams were not mapped due to lack of a file on ephemeral rivers.

### **Zimbabwe**

Most of the land in Zimbabwe is semi-arid to sub-humid with rainfall ranging 200-1200 mm. Thus, RWH is required almost throughout the country. Population is sparsely distributed throughout the country meaning there are many disjointed settlements. These can benefit from rooftop RWH. Runoff harvesting from open surfaces is predicted to be potentially applicable throughout the country but it was not possible to depict the potential areas for sand/subsurface dams.

### **Cost Estimates of RWH Interventions**

Even though the costs of implementing RWH vary with countries and regions, availability of local materials and local operating conditions, basic costs per cubic metre of ware are generally comparable for specified RWH technologies. For the four RWH inventions featured in the GIS database, cost estimates were obtained from published sources, expert consultations and experiences by SEARNET in Eastern African. These have been shown in Table 3.

### **What the GIS Database May Not Show**

Most regular GIS users like to zoom in on a known area to check if the attributes known to them are correctly depicted. For the Africa-scale GIS database developed in this project, zooming in to query detail on a known area is discouraged as it may not yield the expected results because the database is meant for a general continent-wide overview. It will show areas suited to a specific RWH technology by comparing e.g. a Sahelian region and a Saharan region but zooming in on a small region is not useful. For instance, although the database shows areas suited to sand dams, there is no indication of where to site a sand dam. In addition, vegetation and weather are dynamic systems within a given year and these have not been depicted. There was no data to show which areas already have other types of water supply systems, e.g. piped water and these have not been weeded out or shown in the database. The database will be quite useful in guiding users as to where to target RWH projects, at sub-regional/national levels, but actual planning of the activities requires further detailed surveys and consideration of other socio-economic factors.

**Table 3** Typical costs for some rainwater harvesting technologies

(Source: Desta et al, 2005; Nissen-Petersen, 2000)

Technology	Typical example	Cost	Unit
Underground tanks	Concrete dome shaped tank	7	US \$/m <sup>3</sup>
	Brick dome shaped tank	9 to 14	US \$/m <sup>3</sup>
	Bottle shaped tank	4	US \$/m <sup>3</sup>
	Ferrocement tank	12 to 15	US \$/m <sup>3</sup>
	Ballshaped plastic tank	160	US \$/m <sup>3</sup>
Above ground tanks	Brick tank	93	US \$/m <sup>3</sup>
	Ferrocement tank	30 to 70	US \$/m <sup>3</sup>
	Plastic tank	130	US \$/m <sup>3</sup>
Runoff open reservoirs	Plastic lined	3	US \$/m <sup>3</sup>
	Cement lined	5	US \$/m <sup>3</sup>
	Unlined	100	d/ha
	Lined oval tank	8	US \$/m <sup>3</sup>
Runoff closed reservoirs	Concrete dome shaped underground tank	7	US \$/m <sup>3</sup>
	Brick dome shaped underground tank	9 to 14	US \$/m <sup>3</sup>
	Bottle shaped underground tank	4.0	US \$/m <sup>3</sup>
	Ferrocement underground tank	13	US \$/m <sup>3</sup>
	Hemispherical underground tank	23	US \$/m <sup>3</sup>
	Sausage shaped tank with cement lining	16	US \$/m <sup>3</sup>
In situ	Human land preparation	113	h/ha
	Draught Animal Power land preparation	53	h/ha
Sand or sub-surface dams	Sand dam	0.8	US \$/m <sup>3</sup>
	Sub surface dam	0.7	US \$/m <sup>3</sup>
Rock catchments	Open rock dam with stone gutters	71	US \$/m <sup>3</sup>
	Closed rock dam with stone gutters	89	US \$/m <sup>3</sup>
	Open rock dam with tank	110	US \$/m <sup>3</sup>
	Rock catchment tank with stone gutters	46	US \$/m <sup>3</sup>
	Stone gutters	2	US \$/m

*NB: Local material and labour can be provided by the community*

NB

I (BM) find these costs to be rather high compared with my own experiences and those from literature. For instance, according to Nissen-Petersen (2000), subsurface dams in Machakos District of Kenya cost the community about 0.2-0.3\$ per m<sup>3</sup> of water.

## Conclusions

This report forms part of a larger project to show through a Geographic Information System (GIS) that Africa has a huge untapped potential for rainwater harvesting. This information is required for awareness creation and as a decision support tool for targeting RWH plans and investments at sub-regional scales. The reason for using GIS for this type of advocacy is due to the versatility of the tools in developing visual messages that cover the whole continent, and can also be made for country case studies. GIS products are easy to show through posters, reports, briefs or internet, and can be easily updated if new information comes. GIS can also be used to show multiple variables. Since the database covers the entire African continent, it is relevant to a wider audience.

The GIS database was developed by a multi-disciplinary team of hydrologists, engineers, socio-economists and GIS experts, with regular peer reviews by selected

professionals from participating countries. The actual mapping involved data collation from GIS laboratories (particularly ILRI and ICRAF), and non-spatial data from libraries, local and international organizations, individuals and the internet. The major RWH interventions identified for mapping were; (i) rooftop RWH, (ii) surface runoff from open surfaces with storage in pans/ponds, (iii) flood-flow harvesting from watercourses with storages in sand/subsurface dams, and (iv) in-situ soil water storage systems. The major variables used in the mapping were rainfall, population, land use, DEM, slope, soils and ephemeral streams. These variables were reclassified and through GIS map analyses (map calculator), development domains to suit each of the RWH were developed.

A total of 73 thematic maps were developed in this project. These comprise 29 thematic maps of rainwater harvesting potential in Africa and 44 composite maps for the ten country case studies covering Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe. These generally show areas that could benefit from each intervention. At continental and country scales, it was not possible to do detailed mapping, but have a broad-brush "first-bet" scenarios, containing classified composite attributes (legends) called "Development Domains", which tell the user what to find where, and thus provide a decision support tool. Since the major ingredient in rainwater harvesting is rainfall, and based on the fact that if it rains, it can be harvested regardless of the quantities (too little or too much), and the no areas were labeled as either suitable or unsuitable for RWH. Even with the constraints associated with the GIS database developed in this project, it still provides a strong case from a spatial perspective, for advocating for rainwater harvesting as an important contribution towards meeting the MDGs target on water and the African Water Vision.

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SRTM 90 meter DEM CIAT and USGS HYDRO1K digital elevation model, 2000

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## ANNEXES

### Annex 1. Sources of spatial data

Item	Layer	Source	Resolution
All	Rainfall	WorldClim Version 1.3 2004	Global (1km x 1km)
All	National parks	World Conservation Union management categories I-VII, World Conservation Monitoring Centre (WCMC), Cambridge, UK	Continental (shapefile)
All	Country boundary	John Corbett, 2002, The Spatial Characterization Tool (ACT) Africa v.3.5. Texas Agricultural Experiment Station, Texas A&M University, Blackland Research Center Report	Continental (Shapefile)
All	Population	Center for International Earth Science Information Network (CIESEN) 2000	Continental (5km x 5km)
All	Rivers	FAO-UN-AGLW, 2000, Hydrological basins in Africa	Continental (Shapefile)
All	Lakes	FAO, 1998, Land and Water Digital maps series No. 13 "Atlas of Water Resources and Irrigation in Africa	Continental (shapefile)
All	Evapotranspiration	TERRASTAT, 2002, Global land resources GIS models and databases for poverty	Global (5km x 5km)
Africa	Slope	TERRASTAT, 2002, Global land resources GIS models and databases for poverty	Global (5km x 5km)
Countries	DEM	SRTM 90 meter DEM CIAT, USGS HYDRO1K digital elevation model 2000	Global (90m)
Countries	Settlements	John Corbett, 2002, The Spatial Characterization Tool (ACT) Africa v.3.5. Texas Agricultural Experiment Station, Texas A&M University, Blackland Research Center Report	National datasets (shapefile)
Kenya, Uganda, Tanzania	Land use	FAO, 2002-3, Africover Project	National dataset (shapefile)
Ethiopia	Land use	Ministry of Agriculture and Ethiopia Mapping Authority (EMA), 1992, Land use and cover types	National dataset (shapefile)

## Annex 2. Types of GIS Data for mapping of RWH potential in Africa

Criteria	Description	Source
Basin and sub-basin	The layers are dealt with at the watershed level as a hydrological unit	Corbett,2002
Countries	The presentation of the maps is done per country	Corbett, 2002
Rainfall	Rainfall is the main factor to implement RWH. There is low potential for 200-400mm, and high potential for rains above 1200 mm. The range 400-1200mm is considered of medium potential, with the highest priority.	FAO, 2002, TERRASTAT
Topography	A classification of slopes has been done derived fro, the FAO classification: 0-2% Flat; 2-8% Undulating; 8-16% Rolling; 16-30% Hilly; > 30% Mountainous	FAO, 2002, TERRASTAT
Evaporation	Evaporation rates have been considered; E-R>1000mm.	FAO, 2002, TERRASTAT
Soils	Soil types were classified in terms of texture;	FAO, 1978
Land cover	The land cover is mostly used to identify forests where some technologies are not relevant	Global Land Cover 2000 database
Rivers	Seasonal streams and permanent rivers could be differentiated	FAO-UN – AGLW 2000
Population	It has been possible to pull out population densities	Gridded Population of the World 1999- 2000
Farming systems	They helped determine nomad pastoralist areas from others	FAO, World Bank 2001.

### Annex 3. Types of GIS Data for GIS mapping of RWH potential for countries

Criteria	Description	Source
Basin and sub-basin	The layers are dealt with at the watershed level as a hydrological unit	FAO-UN – AGLW 2000
Rainfall	Rainfall is the main factor to implement RWH. There is low potential for 200-400mm, and high potential for rains above 1200 mm. The range 400-1200mm is considered of medium potential.	Ministry of Water
Topography	A classification of slopes has been done derived from the FAO classification: 0-2% Flat; 2-8% Undulating; 8-16% Rolling; 16-30% Hilly; > 30% Mountainous	USGS, 2000
Evaporation	Evaporation rates have been considered to differentiate open to closed storage systems. E-R>1000mm switches to closed systems	Corbett, 2002
Soils	Soil types have been useful to determine suitability of rock catchments and of sand dams;	ISRIC and KSS, 1995
Land cover	The land cover is mostly used to identify forests where some technologies are not relevant	FAO Africover, 2003
Rivers	Seasonal streams and permanent rivers could be differentiated	Corbett, 2002
Lakes		Ministry of Water
Population	It has been possible to pull out household data	CBS 1999
Land use	They helped determine agricultural areas from others	ISRIC and KSS, 1995
Hydrogeology	Gives idea of conventional water supply	JICA, 1992
Districts or Countries		Corbett, 2002

## Annex 4. Available GIS Input data for country Case studies

Country	Rooftop tanks	Runoff ponds/pans	In situ	Sand or sub-surface dams	Base maps
Africa	√	√	√	√	5
Botswana	√	√	x	√	4
Ethiopia	√	√	√	√	5
Kenya	√	√	√	√	5
Malawi	√	√	x	x	4
Mozambique	√	√	x	x	4
Rwanda	x	√	x	x	0
Tanzania	√	√	√	x	5
Uganda	√	√	√	x	5
Zambia	√	√	x	x	4
Zimbabwe	√	√	x	x	4

Maps produced (√) or not (x) out of the 44 planned and number of base maps for each country

## ANNEX 5: Project Team

Name	Institution	Responsibility
Dennis Garrity	ICRAF	Mentor
Maimbo Malesu	RELMA IN ICRAF	Project coordinator
Elizabeth Khaka	UNEP	Project coordinator
Bancy Mati	JKUAT	Technical adviser
Tanguy De Bock	Intern	Project manager
Meshack Nyabenge	ICRAF	GIS specialist
Vincent Oduor	Consultant	GIS specialist
Alex Oduor	RELMA IN ICRAF	Project adviser