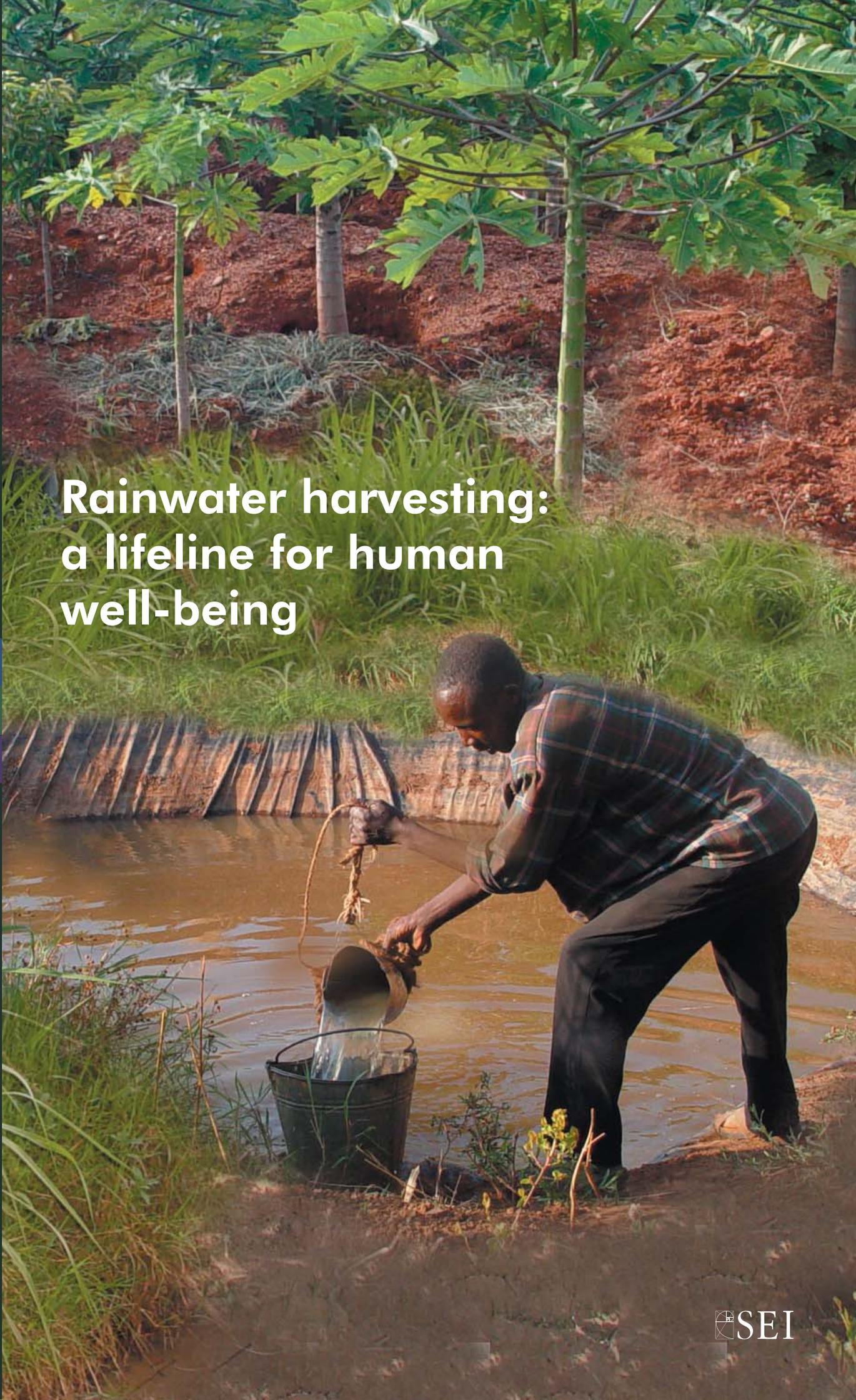




# Rainwater harvesting: a lifeline for human well-being





# **RAINWATER HARVESTING: A LIFELINE FOR HUMAN WELL-BEING**

*A report prepared for UNEP  
by Stockholm Environment Institute*

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## FOREWORD



In 2008 the world witnessed multiple crises including a food one which resulted in unrest in many areas of the world. These tensions may well foreshadow future challenges as they relate to providing sufficient food for six, rising to nine billion people. Unless we get more intelligent in the way we manage agriculture, the world is likely to head into deeply challenging times.

Water and the good and services provided by ecosystems are part of this urgent need for an intelligent management response not least in relation to food production.

The Millennium Ecosystems Assessment report, in which UNEP played an important role, demonstrated the links between healthy ecosystems and food production. These include providing food, water, fiber, genetic material; regulating soil erosion, purifying water and wastes, regulating floods, regulating diseases and pests; and supporting the formation of soil, photosynthesis and nutrient recycling.

Water is an integral part of ecosystems functioning. Its presence or absence has a bearing on the ecosystems services they provide. Relatively larger amounts of water are used to generate the ecosystem services needed to ensure provisioning of basic supplies of food, fodder and fibers. Today rainfed and irrigated agriculture use 7,600 of freshwater globally to provide food. An additional 1,600 km<sup>3</sup> of water is required annually to meet the millennium development goal on hunger reduction which addresses only half of the people suffering from hunger. This figure does not include water required for

domestic, industrial and environmental (environmental flows. With renewable accessible freshwater globally limited to 12,500 km<sup>3</sup>, the managing of water is a great challenge facing humanity. This makes it essential to find sustainable methods for managing water which incorporate all water users (environment, agriculture, domestic and industry) by promoting ecosystems management, resource efficiency, and governance and climate change adaptation.

There are numerous positive benefits for harvesting rainwater. The technology is low cost, highly decentralized empowering individuals and communities to manage their water. It has been used to improve access to water and sanitation at the local level. In agriculture rainwater harvesting has demonstrated the potential of doubling food production by 100% compared to the 10% increase from irrigation. Rainfed agriculture is practiced on 80% of the world's agricultural land area, and generates 65-70% of the world's staple foods. For instance in Africa more than 95% of the farmland is rainfed, almost 90% in Latin America.

The biggest challenge with using rainwater harvesting is that it is not included in water policies in many countries. In many cases water management is based on renewable water, which is surface and groundwater with little consideration of rainwater. Rainwater is taken as a 'free for all' resource and the last few years have seen an increase in its use. This has resulted in over abstracting, drastically reducing water downstream users including ecosystems. This has introduced water conflicts in some regions of the world. For the sustainable use of water resources, it is critical that rainwater harvesting is included as a water sources as is the case for ground wand surface water.

This publication highlights the link between rainwater harvesting, ecosystems and human well being and draws the attention of readers to both the negative and positive aspects of using this technology and how the negative benefits can be minimized and positive capitalized.

*Achim Steiner*

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## CHAPTER 5

### FORESTS WORKING AS RAINWATER HARVESTING SYSTEMS

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#### 5.1. GLOBAL TRENDS IN FOREST COVER

Net deforestation has lost some pace during the last decades, but is still severe in a global context (FAO, 2005). Notably, the range and nature of deforestation is very variable in different regions and countries. In many cases, with intensifying cultivation and conversion to pasture or permanent low-input agriculture, the result is not only loss of biodiversity and its related ecosystem services, but landscapes are at risk of erosion, water pollution, flooding and decreasing soil productivity. These land use and land quality developments are very undesirable from the perspective of meeting the needs for increased biomass production for food and energy, as well as for ensuring a supply of clean water. On the other hand, much less attention is given in the media to the simultaneous processes of increasing forested areas in some regions and the increasing use of planted trees for various purposes. Planted forests have historically contributed to development in many countries in temperate regions, and have the potential to improve the livelihoods of millions of people in other regions. Today, planted forests comprise 6.9% of the world's total forest area of which more than half is located in the South. In 2050, FAO predict that 75% of global wood consumption will come from planted forests and that this expansion will be global. Recent expectations of forests as bio-energy reserves may dramatically raise the demands for new planted forests. 75% of planted forests are intended for industrial production. Forests owned by smallholders increased more than 3 times during 1990-2005 and now represent over 30% of all planted forests (FAO, 2005; 2006). Outside these figures, trees planted outside forests and on homesteads are increasing steadily. Apart from FAO definitions

of planted forests (Table 5.1), this group represents a continuum of use of trees for a variety of purposes in small woodlots, agroforestry and homesteads. Most of the small holder increase is in Asia. In Africa there is a significant increase in timber plantations. In the near and mid-term future, these plantations will continue to expand, driven primarily by the growing demand from China and India. In recent years, both countries have invested heavily in timber plantation holdings, both nationally and overseas.

Agroforestry, or systems of intercropping permanent and annual crops, has gained a positive aura and developed strongly to improve traditional cultivation systems in a broad variety of environments. The relative success of biomass production in planted forestry has in many cases been overshadowed by negative ecosystems impacts and social-institutional issues. Ecosystem services affected include shifts of water use within the landscape and losses of biodiversity when converting from natural forest. When established without consideration of local stakeholders exclusion from previous livelihoods, it has sometimes caused longstanding conflicts. However, as the natural forest cover continues to degrade and decrease, there is an increasing need for planted forests. In the case of smallholders, crop and land tenure policies often do not favour investments by farmers on land out of their control. Improved management and tenure systems are needed for safeguarding the social and environmental values of forests in the entire landscape. This chapter will discuss the link between forests, water and ecosystem services for human well-being. It will provide an introduction to the potentially high values of establishing stable planted forests for "rain water harvesting" as one potential intervention to rehabilitate

**Table 5.1: Definitions of planted forest in the forest continuum from natural forests to single trees.**

FAO, 2007

Naturally regenerated forests			Planted forests			Trees outside forests
Primary	Modified natural	Semi-natural	Planted component	Plantations		
		Assisted natural regeneration		Productive	Protective	
Forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed	Forest of naturally regenerated native species where there are clearly visible indications of human activities.	Silvicultural practices by intensive management: •Weeding •Fertilizing •Thinning •Selective logging	Forest of native species established through planting or seeding, intensively managed	Forest of introduced and/or native species established through planting or seeding mainly for production of wood or non-wood goods	Forest of introduced and/or native species established through planting or seeding mainly for provision of services	Stands smaller than 0.5 ha; tree cover in agricultural land (agroforestry systems, home gardens, orchards); trees in urban environments; and scattered along roads and in landscapes

landscapes, giving examples from tropical semi-arid and humid cases. Also we would like to emphasize the need for development of more varied plantation practices and better understanding of the water-related values of planted forests in the wide range of settings where they are used.

Forests, trees and bushes form specific part of landuse systems. Considering the water balance, trees normally uses more water per area than an annual cereal crop in the very same location. Thus, the ‘old paradigm’ of forests as ‘water towers’ or as ‘water protectors’ is rarely valid in the landscape (Jackson *et al.*, 2005). However, the provisional ecosystem services capacity of a woodlot, apart from water, can outweigh those of the same area being cultivated. In general, the total biomass gain is higher and biodiversity is improved, provisioning a range of produce which can be harvested, often more reliably than annual crop systems. Forests also provide wood and energy. From a regulatory perspective, trees and forests play a significant role in affecting soil infiltration capacity and reducing erosion. They enhance soil quality through litter fall and extensive root systems, and have been shown to act as water purifiers. Trees and forests in many cultures often fall under special local management systems, to ensure their sustainable maintenance. Often, trees and forests are associated

with high aesthetic and spiritual values. Thus, from a comprehensive livelihood perspective, forests and trees in the landscape offers multiple ecosystem services for the water consumed. Many of these products are essential in times of crop failure, when forest products can provide food and income in times of crisis.

## 5.2 FORESTS ECOSYSTEMS AS WATER HARVEST INTERVENTIONS FOR HUMAN WELFARE

It is now an empirically and theoretically well-established general scientific paradigm that forests use more water than lower vegetation and annual crops in rainfed agriculture. Consequently, empirical evidence is strong that cutting forests results in increased stream flows (Bosch and Hewlett, 1982). Typically, when forest cover is regenerated, more rainfall tends to (once again) be partitioned through soil infiltration and to green water (used for food and fibre production), reducing its availability as blue water (available for human consumption) downstream (Farley *et al.*, 2005; Scott *et al.*, 2005).

As a special case in semi-arid areas, old growth forests may work as “sponges” to better retain or recharge groundwater and to maintain dry season stream flow.

This has long been an item for scientific and policy debate (Bruijnzeel, 2004). Forests have been shown to maintain a high soil infiltration capacity by superior litter fall and soil protection (e.g., Bruijnzeel, 1990). Increasing surface runoff after deforestation increases surface run-off and possible soil deterioration, leading to more “blue water,” but water that is often polluted by soil erosion. The higher surface runoff during rainfall events at a deforested location means that less water is contributed to long term groundwater recharge on site during the wet season. Depending on the location, shallow groundwater is often linked to lower lying stream flows, regulating the river base flow during dry seasons. Decreasing shallow groundwater recharge through deforestation may thus deplete surface water sources in times of high demand. The reduction of stream flow after deforestation has often been observed by rural people, but only a few studies have reported the expected long term decline in dry season flows (Bruijnzeel, 1989; Sandström, 1998). Thus, we have some evidence that a “sponge effect” can be lost by deforestation and subsequent soil degradation, but the conclusion can hardly be made general for all semi-arid forest ecosystems.

Based upon evidence on how tree litterfall and soil protection can improve soil quality and reduce surface runoff and erosion (e.g. Hurni and Tato, 1992), the restoration of a “forest sponge effect” has generally been taken for granted (Kaimowitz, 2005). This has been the paradigm behind numerous forest/tree planting projects and one of several drivers for adoption of agroforestry. However, in this case, there are many local witnesses to the fact that new forests often make wells and streams even drier than after deforestation. As for scientific studies in this case, long term studies are scarce. In contrast to the “lost sponge effect” paradigm, the few studies conducted in semi-arid environments all confirm that new forests use more green water than they contribute to blue water in terms of groundwater recharge. This effect of “not enough ground water recharge” is manifested in these studies as generally declining stream flows following (re)forestation (Scott *et al.*, 2005).

High water use by new forests reflects higher production. The new forests established are most often planted exotic species like eucalyptus and pines. They are chosen for their high productivity. Many of the species used are pioneer species in their respective original

ecosystems, and increasingly they are genetically improved for fast wood production, but not necessarily to be water efficient. Furthermore, these new forests are monocultures of vigorously growing young trees in contrast to old growth forest, which are mixes of species, old trees, young trees and treeless gaps. Deep rooted eucalypts are often given as an “example” of the highly water consuming exotics, but a range of other tree species may show similar relative increases in water use, compared to the natural forest in a given site. In South Africa, the water consumption of trees is recognised in water management. To establish a wood lot or plantation requires special permission from local forest and water authorities, and is associated with specific fees and costs as it will decrease water available for other uses in landscape. One reason for increased water consumption in afforested areas is the use of exotic, more water consuming species, compared to the native vegetation.

We conclude that forest water use is often a significant factor in landscape water flows, including surface, sub-surface and downstream. But the specific impact on the water resources of deforestation and afforestation is governed not only by site specific soil and topographic conditions, but also by whether species are native or exotic; whether trees are in large homogenous plantations or in a landscape and stand structure mosaic. The water use and partitioning of a forest stand is also relative to the site’s natural or alternative landuses and water balance flows. Due to the complexity of forests and their impacts on the local water balance, few comprehensive case studies exist for each climatic, vegetative and hydrological response, especially for semi-arid tropical regions with previously forested, now degraded, soils. In contrast the few studies available are from southern Africa and India where former non-forested grasslands and savannas have been afforested. Thus, the lack of data and empirical evidence is seriously challenging our ability to assess potential water balance impacts by deforestation or afforestation in specific landscape contexts.

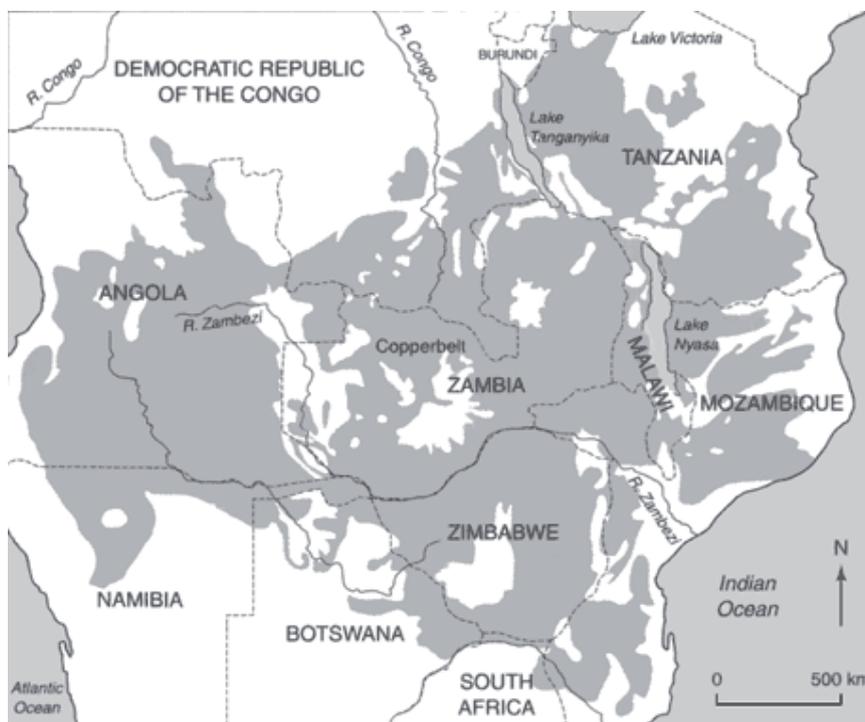
### **Synergies and trade offs in miombo woodlands, southern Africa**

Miombo woodland is a significant biome covering about 10 % of the African landmass (Fig. 5.1), approximately 2.5 – 4 million km<sup>2</sup> depending on definition (White, 1983; Millington *et al.*, 1994). It supports the livelihood of 100 million people in the area or outside, relying on

products from this distinct and unique biome (Campbell *et al.*, 2007). Major provisional ecosystem services essential for livelihoods are charcoal for rural and urban energy, water for downstream needs, wood, meat from grazing and hunting, fruit, tourism, and habitat provision, etc. In addition, the woodland affects several regulatory services, such as landscape water flows, soil erosion control and regeneration of soil health in the smallholder systems. Throughout its physically varied region, miombo woodlands overlap with deciduous forests and open savannahs (Frost *et al.*, 1986). The climate is semi-arid with one wet season, but annual rainfall ranges as much as 550 – 1200 mm and dry season lasts between 3 and 7 months. The miombo woodlands also coincide with some of the poorest sub-Saharan African countries, with relatively low rates of achievement of many Millennium Development Goals relating to water supply and sanitation. The high prevalence of HIV/AIDS among other diseases is a big challenge to the people living in the area.

Deforestation is an old and ongoing process in the miombo region (FAO, 2007), but large areas are still covered by miombo in various states. Long term human impacts are often profound on forest structure and

species composition in many areas (Campbell *et al.*, 2007). Forest management and tree planting mostly has been focussed on exotic species in plantations and woodlots, even if, more recently, there are increasing numbers of interesting examples of natural forest management in Zimbabwe (Gerhart and Nemarundwe, 2006) and elsewhere (Campbell *et al.*, 2007). Tanzania and Zimbabwe are the central concerned miombo countries that have the most forest plantations. Total areas are still moderate and about half of them are industrial (Varmola and Del Lungo, 2002). Looking ahead, with increasing demands for energy, industrial wood and carbon credits, there is a growing interest in plantation forestry in the relatively sparsely populated miombo region, not least in Tanzania (e.g., Stave, 2006). The miombo landscape provides a very varied structure and net primary productivity of the continuum ranges from degraded miombo to well-managed miombo to even-aged forest plantations. This has large impact on water management, both through water use by the trees as well as by the impact on soils and potential groundwater recharge (Malmer and Nyberg, 2008). Any major change in the miombo woodlands needs serious consideration: can the 'sponge effect' be lost? And what implications does that have on provisioning and



**Figure 5.1. Distribution of miombo woodlands, major biome in semi-arid southern hemisphere Africa.**

regulating ecosystem services supporting vulnerable livelihoods in the area?

An example of the altered water balance due to the planting of exotic species is the decreased lower annual and dry season stream flows in areas populated by *Eucalyptus saligna* compared to nearby grasslands in Sao Hill, Tanzania; the stream flow reduction by *Pinus patula* was much less (Mhando, 1991). Thus, planting eucalyptus could potentially mean a loss of biodiversity, and reduced dry season flows. In another study, using long term data, Kashaigili *et al.* (2006) show major decreases in dry season flows (60-70%) between 1958 and 2004, downstream of the Usangu wetlands in Tanzania. In the upstream areas, woodlands have decreased strongly due to expansion of cultivated lands and bare land. In this case it may be tempting to hypothesise on the “lost sponge effect”, but Kashaigili *et al.* (2006) used modelling to show that the major reason for declining dry season flows was due to increase of irrigated agriculture upstream from the wetlands.

#### A healthy soil system is key for catching rainfall

Management of organic material in soils is crucial for a healthy soil system. Soil organic matter influences soil physical characteristics and availability of plant nutrients. Increased soil organic matter increases soil water storage capacity, and water infiltration capacity. Harvesting, grazing and fire lead to degradation by reducing litterfall; i.e., contributing to reduced organic

matter content, and oxidation. In miombo, already low topsoil organic contents are typically reduced by up to 50 % by agriculture (Walker and Desanker, 2004). Soil organic matter also determines top soil physical properties. The soil structure (soil aggregates increasing the amount of large pores) determines to a large extent the partitioning between surface runoff, erosion and soil water infiltration (Bruijnzeel, 1990; Malmer *et al.*, 2005). In various land uses in Zambia, the structural stability of the soil was shown to be positively related to soil organic carbon (King and Campbell, 1993). Soil crusting is a common reason for reduced soil water infiltration in semi-arid areas. Perroll and Sandström (1995) concluded that vegetation cover was the other major determinant apart from soil texture in Tanzania and Botswana. Similarly, Casenave and Valentin (1992), using data from 87 sites in semi-arid West Africa, found intensity of surface sealing, vegetative cover and soil faunal activity to be determinants of soil water infiltration. Organic matter in the soil is highly dependant on vegetation species composition. Research suggests that miombo may not always be superior to exotic species, but the condition of the miombo stand does affect the litter, the soil organic matter and subsequently the infiltration of rainfall (Ilstedt *et al.*, 2007; Ngegba *et al.*, 2001; King and Campbell, 1993; Nord, 2008) (Fig. 5.2).

In the miombo region, like other semi-arid areas, a higher intensity of land use in trees is already leading to environmental degradation. Despite inadequate scientific clarity in regard to the biophysical processes and lack of empirical data, resources have to be managed. Multi-species plantations in general are shown by meta-analysis to be more productive than mono-specific plantations (Piotto, 2008). At the same time these more complex forest stand types might have a more favourable impact on infiltration and a more moderate water demand compared to most even-aged monocultures. In addition, experiences of development of smallholder involvement in forest establishment and management from Asia might be fruitful to apply in the miombo region (Nawir *et al.*, 2007).

#### West African parklands – trees in agriculture generate soil and water gains

Sudano-Sahelian parklands stem from dry deciduous forests with some relation to miombo. These parklands have had strong human influence on the structure of the vegetation for a long time. While small-scale shifting



Typical miombo woodland

Malmer

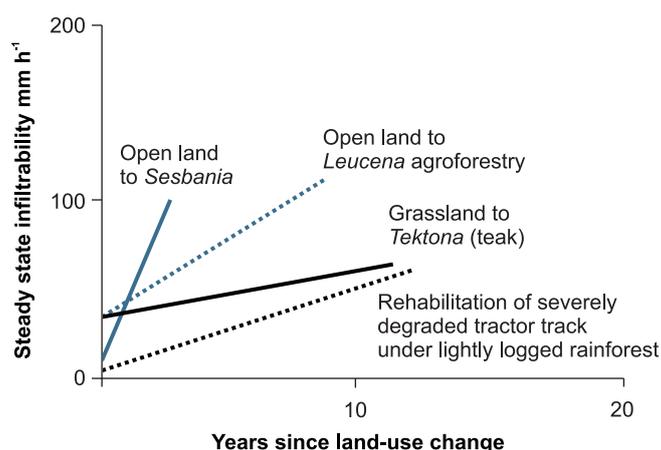
cultivation is dominant in miombo (Campbell *et al.*, 1996), the parkland of West Africa is dominantly under permanent traditional agroforestry with dense wooded savannah. There is an abundance of preferred indigenous tree species (Pullan, 1974). The fallow periods are continuously being shortened because of pressure for land (Boffa, 2000). However, farmers retain trees in farmlands for their own livelihood purposes.

Certain species such as *Vitellaria* provide valuable butter from the kernels of the tree nuts. This is used for local consumption and provides an important source of income for rural women (Kelly *et al.*, 2004). Products from several tree species are also used in traditional medicine and produce edible fruits. However, due to the intensification of agriculture (mainly the use of tractors) in the region, the parklands are decreasing and in many cases the tree cover is diminishing (Nikiéma, 2005). Several studies have shown that trees add soil organic matter through litter fall as well as promoting biological activity in the soil (Young, 1995) and thereby improve the physical properties of the soil (e.g., Traoré *et al.*, 2004). These benefits are similar to the effects of applying compost manure to the fields (Ouédraogo *et al.*, 2001).

Little is known from research about the effects of trees on the water management of the parklands, although vegetative cover in the region is considered to be

important to ensure maximum rainwater infiltration into the soil profile (Casenave and Valentin, 1992; Hansson, 2006). In addition, Bayala *et al.* (2003) concluded from a study carried out in the parklands of Burkina Faso that an application of leaf litter mulch from *Parkia biglobosa* and *Vitellaria paradoxa* prunings improved soil organic matter content as well as water infiltration. More recent Bayala *et al.* (2008) have shown some parkland trees to hydraulically redistribute water during the dry season. This means that the trees at night transport water from deeper soil layers to the top soil. This is beneficial for both the trees and other plants during hot dry season days. However, as for miombo, there has not been clear scientific verification of the effect of the trees on water budgets. The effect on rainfall by re-introducing trees and their management in the parklands also has not been clearly synthesized and interpreted.

On a field scale, *in situ* rainwater harvesting can enhance re-establishment of trees on the landscape. The success of re-greening of the Central Plateau, Burkina Faso (Reij and Smaling, 2008) is an example where land reclamation through *in situ* water harvesting has led to increased numbers of trees on former crop-land (Reij *et al.*, 2003). In this case, the severe droughts generated a positive response in terms of activating communities and mobilizing resources to address multiple challenges including poverty, low crop yields and severe land degradation. Farmers, NGOs, local government and



**Figure 5.2: Examples of efficiency of rehabilitation of water infiltration capacity after planting trees of different species and in different situations: open land to *Sesbania*, open land to *Leucena* agroforestry, grassland to *Tektora* (teak) and rehabilitation of severely degraded tractor track under lightly logged rainforest (after Ilstedt *et al.*, 2007)**

external funders together enabled the adoption of *in situ* rainwater harvesting for growing crops and trees. A few key technologies were particularly interesting such as the *zai* pitting, and the construction of stone bunds and gully control structures. The results of *in situ* rainwater harvesting showed that average crop yields doubled over 20 years, producing more forage leading to increased livestock numbers and establishment of more trees (citing Riej *et al.*, 2003). In addition, species diversity in fauna was regenerated, and a noticeable rise occurred in the groundwater table. Although soil fertility has improved through better soil and water management, there is more potential for improvement. According to the local communities, food security has improved to meet the demand of the population, that has increased by 25% between 1984 and 1996. An important effect of improved yields is that no further crop land expansion has occurred since mid 1980s despite the population growth and improved livelihoods.

### Trees removed in lack of knowledge for total valuation?

Removal of trees and lack of regeneration in the parkland is often driven by the introduction of mechanized farming in a cotton and maize rotation system. This is for increased food production and cash incomes for local communities. However in the long term, this production system may lead to a decline in soil organic matter, fertility, high erosion risk and soil degradation (Lal, 1993). Maintaining soil organic matter is important



**Productive parkland in Sahel**

Malmer

for carbon sequestration and better moisture retention for improved crop harvest (Ouattara, 2007). This is instrumental for climate change adaptation where scenarios indicate drier climates in years to come.

In contrast to increasing demands for higher biomass production and increased crop yields, and in view of the lack of reliable data on trees and their benefits, it is not easy to motivate people on economic and long term benefits of trees in parklands. There is a lack of clear validation systems for evaluating the effect of retaining trees in parklands. Carbon trading systems have not been fully successful in providing this validation, but it is expected that the recognition of such systems in the post-Kyoto protocols for REDD (Reducing Emissions from Deforestation and Degradation) might be one way.

## 5.4 CONCLUSIONS

We conclude that cases of forestry and of a landscape mosaic with trees can be seen as ‘rainwater harvesting interventions’, where the forests and trees provides numerous provisional, regulatory, aesthetic and supporting ecosystem services for sustaining livelihoods and producing economic benefit. The notion of forests being ‘water towers’ is a misconception, as forests and trees actually consume water in generating the ecosystem services. However, this ‘lost’ water creates other benefits in terms of human welfare via the goods and services provided by the forest ecosystems. Depending on local conditions, forest areas can act as sponges, ensuring stable base-flows in downstream river systems, as well as increasing water infiltration into the soil, which can recharge shallow groundwater sources.



**Degraded parklands in Sahel**

Malmer

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However, the cases of water partitioning in semi-arid miombo woodlands and West African parklands cannot be generalized to locations with different species and management strategies. The lack of empirical evidence of linkages between trees, landscapes and rainfall complicates the issue of possible tradeoffs or mutual benefits to be derived from trees, or in terms of ecosystem services and landscape water flows (green and blue water partitioning of rainfall). As Scott *et al.* (2005) express, possibly in most cases, productive forests might use more water than they contribute to groundwater recharge. On the other hand, with increasing demands for high levels of production of both wood and food, the alternative, with continued deforestation and continued deterioration of forests, parklands and their soils, is hardly a viable alternative.

transport are all complementary benefits for a local community. However, extensive land-use changes from forests to plantations or to decreased forest cover should always be weighed within a comprehensive impact assessment of both environmental and social-economic issues, including the landscape water balance.

The ‘rainwater harvesting’ effect of trees and forests is turned into valuable goods and services and is also linked to the impact on the soil surface and the actual consumption of water. Trees generate litter, which improves the organic matter content in soils - a key component to increased water infiltration. Secondly, trees reduce rainfall impacts on soil surfaces that control soil erosion and sediment transport. Although there is limited empirical data on water balances and forests, the well-known benefits of forest ecosystem services can offer a positive regeneration of degraded and water stressed landscapes. Improved provisioning of goods and services as wood, fodder, fruit, medicines, sometimes water flows as well as habitats for diverse flora and fauna are all components that are enhancing the livelihoods of smallholder farmers. Additional benefits such as water purification, build-up of fertile soil systems, and reduced flooding and sediment



*Sahelina parkland Mali*

Enfors

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