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Benefits of rainwater harvesting for gardening and implications for future policy in Namibia

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Abstract

Rainwater harvesting to irrigate small-scale gardens enhances food self-sufficiency to overcome rural poverty. So far rainwater harvesting is not encouraged by the Namibian National Water Supply and Sanitation Policy nor supported financially by the Namibian government. This study proposes two rainwater harvesting facilities to irrigate gardens; one collects rain from household roofs with tank storage, the second collects rain on a pond roof with pond storage. The aim of this paper is to assess the benefits of rainwater harvesting-based gardening and to propose policy and financing implications for the Namibian government. We investigate the benefits of rainwater harvesting through a literature review, a cost–benefit analysis, monitoring of project pilot plants and a comparison with the existing irrigation and drinking water infrastructure. The results indicate that rainwater harvesting offers numerous benefits in technological, economic, environmental and social terms. The facilities have a positive net present value under favourable circumstances. However, material investment costs pose a financing problem. We recommend that government fund the rainwater harvesting infrastructure and finance privately garden and operation and maintenance costs. Integrating these aspects into a national rainwater harvesting policy would create the conditions to achieve the benefits of an up-scale of rainwater harvesting based gardening in Namibia.

Keywords: Benefits; Central-northern Namibia; Cost–benefit analysis; Financing; Gardening; Rainwater Harvesting; Roof and ground catchments; Water policy; Water supply

1. Introduction

Rainwater harvesting for the irrigation of household gardens buffers the dry season and droughts (van Steenbergen & Tuinhof, 2009). Rainwater harvesting consists of a wide range of technologies that can be divided into *in situ* and *ex situ* techniques to collect and store water (Barron, 2009). *In situ* rainwater harvesting are soil management strategies that enhance rainfall infiltration and reduce surface runoff,

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such as terracing, pitting or conservation tillage practices. The rainwater capture area is within the field where the crop is grown and the soil serves as a capture and storage medium at the same time. *Ex situ* technologies have capture areas external to the point of storage, being a natural soil surface with limited infiltration capacity or an artificial surface with low or no infiltration capacity. Commonly used impermeable surfaces are represented by rooftops, roads, pavements and slopes. Storage systems are often wells, dams, ponds or cisterns (Barron, 2009).

Owing to increasing water scarcity worldwide, in recent decades rainwater harvesting has experienced rapid expansion in many countries around the world (Barron, 2009). Especially in semi-arid regions, governments have promoted rainwater harvesting to raise agricultural yields and bridge dry periods. Examples include the Laikipia District in Kenya (Hatibu & Mahoo, 1999; Malesu *et al*., 2006), the Western Pare Lowlands in Tanzania (Senkondo *et al*., 2004), Rajasthan and Gujarat in north-western India (Agarwal *et al*., 2001) and the Gansu Province in north central China (Li *et al*., 2000; Barron, 2009). These regions are characterised by a semi-arid climate with short rainy seasons, high annual potential evaporation, severe seasonal droughts and water shortages and low agricultural productivity. South Africa and the Indian state of Rajasthan have already integrated rainwater harvesting into their national water policy (DWAF, 2004; Mwenge Kahinda et al. 2007; UN-HABITAT & Government of Madhya Pradesh, 2007). A general precondition to make rainwater harvesting practically and economically feasible is an annual precipitation of at least 300 mm, unless other sources are extremely scarce (Worm & van Hattum, 2006).

Namibia is the driest country in sub-Saharan Africa. In central-northern Namibia annual rainfall ranges from 300–600 mm, 96% falling from November to April (Heyns, 1995; Kluge *et al*., 2008; Sturm *et al*., 2009). The area is characterised by a semi-arid climate with short rainy seasons, high precipitation variability, alternating droughts and floods, ephemeral river systems and brackish or saline groundwater (Heyns, 1995). Presently, most drinking water is abstracted from a reservoir, the Calueque Dam in Angola on the perennial Kunene River that is shared between Angola and Namibia, and transported through an extensive grid of canals and pipelines. Most settlements in the region have access to such supplies in sufficient quantity to serve their drinking water requirements (Heyns, 1995). However, there is no infrastructure to supply irrigation water to rural communities. Many poor households depend on rain-fed subsistence farming during the rainy season to secure their livelihoods (Republic of Namibia, 2006; Republic of Namibia, 2008b). In rural and remote areas the incidence of poverty is particularly pronounced with 38% of the population being poor (Republic of Namibia, 2008a). Agricultural yields are generally very low, leaving many households vulnerable to food insecurity and inadequate food supplies (Republic of Namibia, 2008b; Werner, 2011). A survey conducted by the Food and Agricultural Organization showed that many inhabitants, especially women, wish to extend their garden activities. However, the biggest limiting factor is the lack of sufficient and affordable water for irrigation. Thus most respondents stated that they need help to collect rain (Dima *et al*., 2002). The Namibian Third National Development Plan (NDP3) recognised the low and erratic rainfall and the poor soil quality of the region to be major impediments to a meaningful poverty reduction (Republic of Namibia, 2008b). While the Government of Namibia has responded by developing a comprehensive policy framework to promote household food security, insufficient attention is given to encourage micro- to small-scale local food production (Werner, 2011). Current policies and legislation encourage the use of alternative water sources (Republic of Namibia, 2008a). During the 1950s and 1960s several attempts have been made to harvest rain in uncovered pump storage dams in central-northern Namibia. However, owing to poor water quality, caused by evaporation, pollution and salinisation, the dams fell into disrepair (Driessen & Jokisch, 2010). New investments in more appropriate rainwater harvesting infrastructure could have a broad range of benefits and give essential impetus for the regional economy and poverty reduction. However, in spite of its potential in Namibia, rainwater harvesting has so far not been considered in the current National Water Supply and Sanitation Policy (Republic of Namibia, 2008c) nor in the latest Water Act (Republic of Namibia, 2004).

The aim of this study is to assess the benefits of rainwater harvesting in irrigating small-scale gardens and to propose policy and financing implications for Namibia. In addition, the goal was to draw possible generalisations and broader implications for other regions. The study summarises the benefits identified in previous studies and presents research results of a cost–benefit analysis and first monitoring results for the most promising pilot rainwater harvesting facilities. The amount of investment and number of created jobs related to an up-scaling of rainwater harvesting is modelled and considered in relation to existing Namibian investment in irrigation and drinking water supply. Financing problems are revealed and a financing concept and policy implications are proposed to up-scale the technology in Namibia.

2. Pilot rainwater harvesting facilities in central-northern Namibia

The project CuveWaters[1] introduced three different options for *ex-situ* rainwater harvesting in central-northern Namibia. The pilot plants were built in the villages Epyeshona and Iipopo in the Oshana region and were conceived based on a preliminary literature research (Gould & Nissen-Petersen, 2006), a participatory demand-responsive approach with local communities (Deffner & Mazambani, 2010; Deffner *et al.*, 2012; Zimmermann *et al.*, 2012) and consultations with Namibian ministries and the Namibian Desert Research Foundation. During this process the pilot plants were adjusted to local needs and wishes in terms of size, combinations and materials. The three introduced facilities differ in terms of harvesting surface and storage media; the first consists of a corrugated iron roof (100 m^2) and a tank (30 m^3) either made of ferrocement, bricks or polyethylene. Such tanks can be used for single households and public buildings (schools, clinics, etc.) and are sufficient to irrigate up to 90 m^2 of cultivated garden area. A second pilot facility collects rainwater from a concrete ground catchment (480 m^2) and a greenhouse roof (160 m^2) and stores the water in a covered underground ferrocement tank (120 m^3) and a covered and sealed pond (80 m^3). The stored water irrigates an outside garden (900 m^2) and a greenhouse (160 m^2) jointly used by six households. A third pilot facility collects rainwater from nearby ephemeral rivers, so-called Oshanas, at the height of the rainy season and stores the water in a covered ferrocement underground tank and a pond with a combined storage capacity of 400 m^3. The stored water is sufficient to irrigate a 1,000 m^2 outdoor garden area and a greenhouse of 176 m^2, which are jointly managed by ten households. The Oshanas are difficult to use for permanent irrigation owing to high evaporation rates and therefore quick quality degradation and thus salinisation of the water.

This study assesses the two most promising rainwater harvesting facilities based on a preliminary assessment of the pilot plants (Jokisch *et al.*, 2011). The first is the ferrocement tank with roof catchment at household level as piloted in Epyeshona village (Figure 1). The second is the pond with roof catchment at community level which is an optimal combination of piloted facilities in Epyeshona based on project experience and costs (Figure 2; Table 1). The possible duration of irrigation of gardens

[1] http://www.cuvewaters.net.

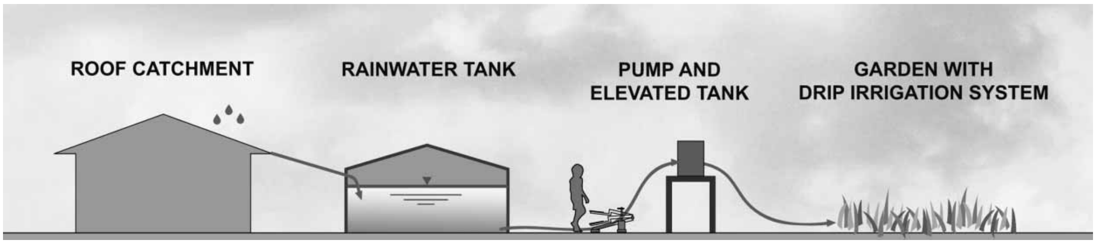

Fig. 1. Rainwater harvesting with roof catchment and ferrocement tank at household level.

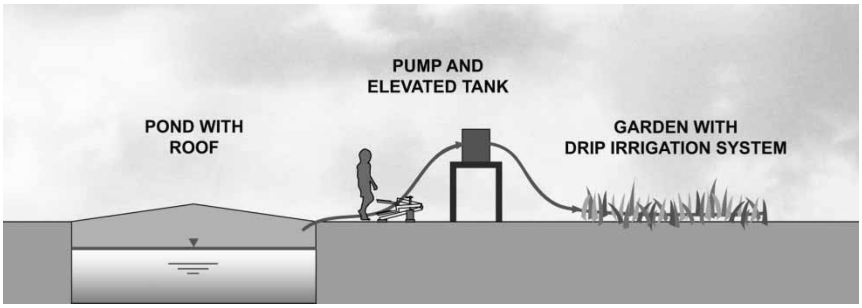

Fig. 2. Rainwater harvesting with roof catchment and pond at community level.

Table 1. Proposed rainwater harvesting options in central-northern Namibia.

Rainwater harvesting option	Tank material	Catchment material	Catchment area (m^2)	Storage volume (m^3)
Tank with roof catchment household level	Ferrocement	Corrugated iron	100	30
Pond with roof catchment community level	Dam liner	Corrugated iron	285	80

with harvested rainwater depends on the irrigation technique, cropping pattern, garden area and the extent of the rainy season. Considering these factors, the stored water is sufficient for the irrigation of one or two additional annual growth seasons. In the project region, rainwater harvesting is meant to enhance the water supply for the productive irrigation of small-scale gardens and not to serve as a substitute for drinking water. However, in remote areas far from the existing pipeline grid harvested rainwater could also be treated and serve as drinking water.

3. Methodology

3.1. Benefits of rainwater harvesting for gardening

The benefits of rainwater harvesting were assessed through a literature review and categorised in technological, economic, environmental and social terms. In this section, non-market benefits were listed in a qualitative manner since placing monetary values on environmental and social non-market costs and benefits is extremely difficult, controversial and not always meaningful (Atkinson & Mourato, 2008).

3.2. Financial cost–benefit analysis

In this section, we assessed the financial benefits of rainwater harvesting-based gardening in monetary terms. We carried out a financial cost–benefit analysis by identifying monetary costs and benefits of rainwater harvesting and gardening for a household or micro-entrepreneur. A cost–benefit analysis involves the identification of costs and benefits occurring over the economic life of a project (Gilpin, 2000; Pearce *et al*., 2006; Ward, 2012). The common method of reducing costs and benefits over the lifespan of a facility to a unique value is the net present value (NPV) method (LAWA, 2005; Pearce *et al*., 2006). Key steps are first to identify the costs and benefits of a project, second to quantify costs and benefits in monetary terms as far as possible and third to discount costs and benefits over the lifetime of the project with a selected discount rate. In purely economic terms, the production of a good is economically justified when the total benefits exceed the total costs (Gilpin, 2000). Benefits correspond to the value of gardening produce at market prices, while costs are equal to expenses. A medium discount rate of 5% was used over an estimated life span of 40 years for the ferrocement tank and 20 years for the pond. These values are based on experiences made by the responsible Kenyan rainwater harvesting consulting company 'One World Consultants' (Kariuki, 2012, personal communication) which has constructed more than 100 rainwater harvesting tanks and ponds in several countries in eastern and southern Africa. The NPV has been calculated as Equation (1) (LAWA, 2005):

$$NPV = -I_0 + \sum_{t=1}^{T} R_t \bullet (1+i)^{-t} \tag{1}$$

where NPV = net present value, I = investment, t = time period from 0 to T, R_t = inflow-outflow in period t, T = time horizon (life span), and i = discount factor. The costs of a rainwater harvesting and gardening facility include material investment costs, labour construction costs and operation and maintenance costs. Material costs include the tank, the pipes and gutters for the roof, the garden fences and the drip irrigation system, Operation and maintenance costs include annual materials costs for spare parts, seeds, fertilizer and pesticides. In a first step, we conducted a cost–benefit analysis including all these costs. In a second step, to show the potential for a more positive cost–benefit ratio, we included only labour, garden material, operation and maintenance costs and excluded the material costs for the rainwater harvesting facility. We calculated with material costs that occurred during the pilot construction phase, operation and maintenance costs were estimated based on local costs and first project experience during the pilot phase. Additionally, we estimated material costs without the conditions of the project.

Financial benefits, the revenue from gardening products at market prices, were modelled based on crop yields, local irrigation requirements, garden area and local market prices. Crop yields were taken as indicated by Price Waterhouse Coopers (2005). Possible garden areas to irrigate with the harvested rainwater were calculated with modelled local irrigation requirements. Specific crop water requirements were calculated with local climate data using the Food and Agricultural Organisation (FAO) software CROPWAT 8.0 (FAO, 1992). A drip irrigation system efficiency of 0.75 was used assuming a conveyance efficiency of 0.85 and an application efficiency of 0.9, calculated according to Brouwer *et al.* (1989) In a preliminary assessment four garden variants considering the amount of annual harvested rainwater were modelled (Woltersdorf *et al.*, 2013). The garden size was fitted so that the rainwater harvesting facilities are sufficient for full irrigation with a frequency of 3 out of 4 years, a probability level recommended as appropriate by the FAO (Savva & Frenken, 2002). This study presents a subsistence and a market garden variant. The market scenario contains tomatoes planted in the pilot village Epyeshona, modelled assuming one annual growth cycle with a market price monitored in the market of Epyeshona in 2011. The subsistence garden variant contains vegetables and fruits suitable for household consumption; the surplus can be sold at local markets, planted for two annual growth cycles (Woltersdorf, 2010). Owing to the lack of local market prices, prices were assumed as indicated by Price Waterhouse Coopers (2005) which presents wholesale market prices for imported horticulture products from January to December 2003 to Namibia in N$ per ton. The follow-up study from Price Waterhouse Coopers in 2008 (Price Waterhouse Coopers, 2008) was not used to owing to the unavailability of all data needed. In addition, the CuveWaters Project monitors local prices, which are, however, inconsistent so far owing to the lack of experience of the rainwater harvesting tank owners. In both garden variants yields and revenues are determined to be achieved in 3 out of 4 years, when the garden area can be fully irrigated. In 1 out of 4 years, owing to natural precipitation variability, precipitation is lower and not sufficient to irrigate the garden area fully and therefore yields and revenues will be lower; this is not presented in this study. Further detail regarding garden variants, precipitation probability analysis and calculation of irrigation requirements exceeds the scope of this paper and is provided by Woltersdorf *et al.* (2013).

3.3. Monitoring pilot plants

The rainwater harvesting pilot plants were monitored in terms of maintenance effort and costs, water use and gardening input and output among other criteria. Most data were monitored by tank owners, while some data were also monitored by project team members. This paper presents the first monitoring results from the pilot village Epyeshona of yields of harvested vegetables and local market prices achieved in 2011. Monitored market prices were compared to market prices used in this study for the cost–benefit analysis indicated by Price Waterhouse Coopers (2005).

3.4. Comparison of rainwater harvesting facilities to the Namibian green scheme project

The Namibian government plans to implement an ambitious agricultural project known as the green scheme project (Republic of Namibia, 2008d). In order to put our proposed rainwater harvesting and gardening infrastructure in the light of the local situation, rainwater harvesting and associated garden facilities were compared to the envisaged Namibian green scheme project. The emphasis is to estimate an order of magnitude and to put these different infrastructures in relation to each other rather than calculating accurate absolute numbers. Information about the green scheme was taken from the literature (Weidlich, 2007; Republic of Namibia, 2008d). Over the next 15 years the green scheme plans to create 11,750 full time equivalent jobs. This study calculated how many rainwater harvesting facilities and gardens would need to be constructed to create the same number of 11,750 jobs. Then the green scheme and the rainwater harvesting and garden facilities were compared in terms of required investment and investment per job. For comparability, only investment costs of labour and material were included over a time span of 15 years. Assumptions and estimations are based on the pilot construction phase of the CuveWaters project. The same market and subsistence planting schemes as designed for gardens irrigated with harvested rainwater were transferred to the envisaged area of the green scheme. Owing to the lack of further data about the green scheme, such as operation and maintenance costs, a NPV calculation was not possible.

3.5. Financing of rainwater harvesting facilities

Financing rainwater harvesting and garden infrastructure is the determining criterion for an up-scale of the technology. These costs were related to the household income in central-northern Namibia in order to determine the possibility of financing these infrastructures. We evaluated the possibility of financing rainwater harvesting facilities with microcredits and proposed financing possibilities.

4. Results

4.1. Benefits of rainwater harvesting for gardening

Rainwater harvesting for gardening offers numerous benefits to local communities in technological, environmental, social and economic terms (Table 2). While rainwater harvesting-based gardening broadly effects and stimulated the regional economy, livelihood benefits extend far beyond material gain. Therefore the technology has the potential to become an important part of Namibia's water infrastructure.

During the construction of the pilot tanks, a team of tank technicians, known in the region as the 'Blue Team', have been enabled to build new tanks and operate and maintain existing tanks, plan budgets, calculate costs and procure construction materials. The technicians proved their skills in constructing a privately financed tank in the absence of the CuveWaters staff. Tank users were trained in proper tank operation and maintenance, gardening and irrigation techniques. Trained technicians, tank users and farmers were highly committed owing to community involvement from the very beginning. The pilot rainwater harvesting facility soon became locally known as the 'Epyeshona Green Village' and represents a local success story receiving considerable attention from the media and people from surrounding villages.

Nevertheless the implementation of small-scale water infrastructure is associated with certain risks and challenges. In rural parts of Namibia, like in most other parts of rural Africa, the low level of education makes it extremely difficult to implement the necessary structures to run gardening ventures that aim to supply markets in the region. Training and education is also essential to counter the lack of knowledge of horticultural production in the region. An additional challenge for planning gardens irrigated with rainwater harvesting is the high rainfall variability in the region (UNEP, 2006).

4.2. Financial cost–benefit analysis

4.2.1. Cost. The costs of pilot rainwater harvesting facilities and estimated costs without project conditions are shown in Table 3.

Table 2. Benefits of rainwater harvesting.

Area	Benefits of rainwater harvesting and gardening	Source
Technology	• Maintenance is easy, therefore the technology is also appropriate for remote rural areas • Local water resources are used instead of inter-basin water transfer	Li *et al.* (2000)
Economy	• Broad spill-over effects for the regional economy (e.g. knowledge extension for rainwater harvesting and gardening) • Job creation and income generation in poor rural and peri-urban communities through • Tank and garden construction, maintenance • Local market sale of crops • Education of tank builders, gardeners, etc. improves own (career) prospective for future life • Productive use of rainwater • Higher crop yields • Extended annual planting season of crops through irrigation into the dry season • Possible to plant crops with a longer growth period and higher water requirements (i.e. tomatoes, cabbages) • Additional annual harvest during the dry season achieves higher revenues	Agarwal *et al.* (2001); Senkondo *et al.* (2004); Yuan *et al.* (2003); Rockström *et al.* (2002)
Environment	• Adaptation strategy to climate change and climatic variability • Effective use of heavy rainfall events • Bridge the dry season • Higher crop growth security by bridging rainfall variations and dry periods during the rainy season • Provides additional water supply reducing pressure and demand on surrounding surface water • Contributes to the regeneration of landscapes by increasing biomass for food, fodder, fibre and wood for human consumption	Pandey *et al.* (2003); Barron (2009); Rockström *et al.* (2002); UNEP (2006); Ngigi *et al.* (2007); Jianbing *et al.* (2010); van Steenbergen & Tuinhof (2009); Barron (2009); Li *et al.* (2000); Machiwal *et al.* (2004); Barron (2009)
Social	• Improved food-security and availability particularly during the dry season • Increased household and community self-sufficiency • Improvement of living conditions for vulnerable or marginalised groups through a better diet and the possibility to engage in a productive activity • Time saved for productive activities through availability of water near the house • Improvement of children's education and health conditions due to additional income • Enables communities to adapt to droughts and declining availability of drinking water • Creation of knowledge and capacity building	Wakefield *et al.* (2007); Wills *et al.* (2010); Swanwick (2009); van Averbeke (2007)

Table 3. Costs of rainwater harvesting and gardening facilities in central-northern Namibia.

Type of facility	Material (N$)[a]			Labour construction (N$)[b]	Operation and maintenance per year (N$/yr)
Ferrocement tank (30 m^3)	School (under specific project conditions)	13,592	Ferrocement, gutters, pipes	5,500	100
	Household (under specific project conditions)	18,571			
	Without specific project conditions, estimated down (see below)	12,000			
Garden	Market: 1 crop cycle/yr (52 m^2)	2,572	Fence, drip irrigation, pedal pump, tools, (shade net)	none	200 (material) 560 (seeds, pesticides, fertilizer)
	Subsistence: 2 crop cycles/yr (84 m^2)	3,320			200 (material) 100 (seeds, pesticides)[c]
Pond (80 m^3)	Community	48,766	Timber, dam liner, Corrugated iron sheet, gutters, pipes	8,100	155
	Estimated down	35,000			
Garden	Market: 1 crop cycle/yr (229 m^2)	6,615	Fence, drip irrigation, pedal pump, tools, (shade net)	none	400 (material) 1,550 (seeds, pesticides, fertilizer)
	Subsistence: 2 crop cycles/yr (148 m^2)	4,808			400 (material) 300 (seeds, pesticides,***)

[a]Currency exchange rate: 1 N$ = € 0.07625 (oanda.com, on 17 September 2013).
[b]Labour costs are calculated with Namibian union labour tariffs of 100 N$/day.
[c]Subsistence farmers are assumed to use goat manure as fertilizer.

The major cost component of a rainwater harvesting and garden facility are the material costs of the rainwater harvesting facility. The market garden contains a shade net, while the subsistence garden does not, as it contains fruit trees for shade. Costs for garden material and operation and maintenance costs are relatively low, for example because only pedal pumps are used for pumping the stored water into the irrigation system. It has to be considered that during the pilot construction phase material costs were extraordinary high, as the project was forced to build during a specific and limited timeframe before holidays and during the rainy season. During this period market prices are higher and, because Oshanas were flooded, the sand had to be purchased. Therefore prices are not transferable to 'without project' conditions and costs are expected to decrease down to an estimated 12,000 N$ for the ferrocement tank and 35,000 N$ for the pond if construction takes place at a greater scale without project conditions (i.e. built by locals in the dry season with optimised material use). In addition, government bulk purchase of important raw materials such as wood, steel and cement might drop current monopoly prices considerably.

4.2.2. Benefit. The ferrocement tank achieves annual revenues from gardening of 5,053 N$ (457 €) (337 kg tomatoes) in the market garden variant and 1,143 N$ (103 €) (548 kg of fruit and vegetable) in the subsistence garden variant (Table 4). The pond achieves annual revenues from gardening of

Table 4. Revenues per year of gardening products from rainwater harvesting with different garden variants.

	Crop type	Planting date[a]	Harvesting date[a]	Cultivated area (m^2)	Local yield per area[b](kg/m^2)	Price[b] (N$/kg)	Gross irrigation requirement[a] (m)	Production (kg)	Revenue (N$)
Ferrocement household tank (30 m^3) with roof catchment (100 m^2)									
Subsistence (worst case)	Water melon	1 Jan	21 Mar	17	5.0	1.07	5.0	86	91
	Cucumber	1 Jul	13 Oct	17	4.0	5.47	10.1	68	372
	Cabbage	1 Jan	14 Jun	17	3.1	0.96	12.9	53	51
	Pepper	1 Dec	30 Mar	17	1.4	6.13	10.8	24	146
	Tomato	15 Apr	2 Sep	17	4.0	2.91	13.8	68	198
	Potato	1 Apr	24 Jul	17	5.2	1.54	8.6	88	136
	Orange[d]	1 Jan	31 Dec	1	23.0	0.92	25.5	161	149
	Sum/year			52			86.7	548	**1,143**
Market (best case)	Tomatoes	1 Jan	4 Jun	84	4.0	15.0[c]	63.9	337	**5,053**
Pond (80 m^3) with roof catchment (200 m^2)									
Subsistence (worst case)	Water melon	1 Jan	21 Mar	48.2	5.0	1.07	14.1	243	259
	Cucumber	1 Jul	13 Oct	48.2	4.0	5.47	28.5	193	1,055
	Cabbage	1 Jan	14 Jun	48.2	3.1	0.96	36.5	151	145
	Pepper	1 Dec	30 Mar	48.2	1.4	6.13	30.6	67	413
	Tomato	15 Apr	2 Sep	48.2	4.0	2.91	39.2	193	562
	Potato	1 Apr	24 Jul	48.2	5.2	1.54	24.4	249	385
	Orange[d]	1 Jan	31 Dec	3	23.0	0.92	1.5	345	318
	Sum/year			146			174.9	1,442	**3,138**
Market (best case)	Tomatoes	1 Jan	4 Jun	229	4.0	15.0[c]	174.1	918	**13,774**

[a]The planting and harvesting date has been determined based on Savva & Frenken (2002) with the growth season coinciding with the rainy season. The gross irrigation requirement has been calculated with Cropwat 8.0 based on local climate data from Ondangwa station; data: Namibian Weather Bureau and crop data for semi-arid regions Savva & Frenken (2002). The area is fitted with probability of tank failure determined to occur in 3 out of 4 years (Woltersdorf *et al*., 2013).
[b]Data: Price Waterhouse Coopers (2005).
[c]Data: project monitoring of market price in Epyeshona village in 2010.
[d]The orange fruit tree is assumed to occupy 1 m^2 on the ground and 6 m^2 at the treetop.

13,774 N$ (1,247 €) (918 kg tomatoes) in the market garden variant and 3,138 N$ (284 €) (1,442 kg of fruit and vegetable) in the subsistence garden variant.

4.2.3. Cost–benefit. The NPV of both rainwater harvesting facilities is negative when assuming subsistence garden production and integrating the material costs of the rainwater harvesting facility (Table 5). Assuming a market garden production, both facilities have a positive NPV: the ferrocement tank of +46,943 N$ (4,248 €) and the pond of +95,711 N$ (8,662 €). Subsistence garden production can also have a positive NPV when excluding the material costs of the rainwater harvesting facility, while still including labour costs for rainwater harvesting facility construction, operation and maintenance (O&M) costs and garden material costs. In this case, the ferrocement tank has a NPV of +6,997 N$ (633 €) and the pond of +25,578 N$ (2,315 €). Further research results for the CuveWaters project clearly show that in remote villages of central-northern Namibia (e.g. more than 65 km distance from the pipeline scheme) the construction of an adequate number of rainwater harvesting tanks can be considerably cheaper than a connection to the pipeline scheme (Jokisch *et al.*, 2011).

4.3. First results from monitoring

Pilot rainwater harvesting tanks and gardens were built in the village of Epyeshona in 2010; a drip irrigation infrastructure was added in 2011. The first harvest in 2010 included butternut, spinach and different varieties of pepper. Gardening products served household consumption and achieved good prices on local markets contributing to household income generation. Since February 2011, the farmers monitor the amount of harvest, income, amount of fertilizers and pesticides applied on the fields. The most popular crop so far is spinach, mainly because it can cope well with the poor soil conditions and grows fast. In 2012, individual household farmers earned up to 900 N$ per month from the sale of spinach. In the greenhouse, tomatoes performed best, as they can be harvested over a long period and generate the highest income. On local markets these tomatoes achieved a mean price of 13 N$/kg compared to 2.91 N$/kg indicated by Price Waterhouse Coopers (2005). In 2012 the farmers focused mainly on spinach and tomatoes based on their experiences in 2011 and stabilised their income from the individual gardens at around 900 N$ per month from the sale of spinach and tomatoes, but in parallel also produced certain other crops for their own consumption thus improving their own diet and health situation. Furthermore the daily water use decreased as a consequence of more experience and knowledge gained in 2011. So far

Table 5. Cost–benefit analysis of two rainwater harvesting options in combination with gardening assuming best case costs (estimated in case of large-scale production), with discount rate of 5%.

		NPV (N$)	
Rainwater harvesting option	Garden variant	Including: material investment costs, labour construction costs, O&M costs	Including: labour construction costs, O&M costs, excluding: material investment cost
Ferrocement tank ($30\ m^3$), lifespan 40 years	Subsistence ($52\ m^2$) Market ($84\ m^2$)	−10,503 +46,943	+6,997 +64,443
Pond ($80\ m^3$), lifespan 20 years	Subsistence ($146\ m^2$) Market ($229\ m^2$)	−17,521 +95,711	+25,579 +138,811

monitoring shows that revenues used in the worst case garden variant are (partly) underestimated, as real income is considerably higher than expected. This is mainly due to higher prices on local markets in central-northern Namibia compared to wholesale prices in the capital Windhoek, used in the Price Waterhouse Coopers (2005) study. Nonetheless, observed water use was higher than calculated and fluctuated considerably over the course of the season, mainly owing to the little experience of the users.

4.4. Comparison of rainwater harvesting facilities to existing water and irrigation infrastructure in Namibia

In 2003 the Namibian government adopted its green scheme policy through the Ministry of Agriculture, Water and Forestry (MAWF). The green scheme's objectives are to increase commercial large-scale irrigated crop production, import substitution, self-sufficiency, food security at national and household level and create jobs (Weidlich, 2007; MAWF, 2008; Republic of Namibia, 2008d). The scheme aims to put an area of approximately 27,000 hectares under irrigation over a period of 15 years (Republic of Namibia, 2008d; Allgemeine Zeitung Namibia, 2011). Irrigated crops include maize, wheat, pearl millet (mahangu) and vegetables mainly along perennial rivers at Namibia's borders (Weidlich, 2007). For project realisation, over the next 15 years the Namibian government aims to invest 3,311 million N$ and 7,430 million N$ are expected to be contributed by the private sector (Weidlich, 2007; Allgemeine Zeitung Namibia, 2007). According to government estimates the green scheme could create 10,000 permanent and 3,500 seasonal jobs. However funding is a permanent constraint and the major reason for slow progress (Weidlich, 2007). In 2007, Namibia had 9,000 ha under irrigation, including 3,000 ha under the green scheme (Weidlich, 2007). Table 6 puts the proposed rainwater harvesting technology in relation to the Namibian green scheme in terms of total investment, created jobs, irrigated area, estimated value of garden produce and investment per job.

We estimated the amount of rainwater harvesting facilities and gardens that can be constructed and cultivated when creating the same number of 11,750 full time equivalent jobs as planned under the

Table 6. Comparison of gardening with rainwater harvesting and the Namibian green scheme (over 15 years' investment), assuming the creation of 11,750 full-time equivalent jobs per technology option.

	Green scheme	Ferrocement rainwater harvesting tank	Rainwater harvesting pond
Amount of RWH facilities and gardens that can be constructed, creating circa 13,500 jobs over 15 years	–	21,875	22,500
Total investment (million N$)	10,741 million N$	747 million N$ (626 million N$ material costs, 120 million N$ labour costs)	1,119 million. N$ (936 million N$ material costs, 182 million. N$ labour costs)
Irrigated area (ha)	27,000 ha	114 to 184 ha	328 to 515 ha
Estimated value of horticulture produce assuming same crop schemes (million N$/year)	3,150 million N$ to 5,264 million. N$	25 million N$ to 111 million N$	71 million N$ to 310 million N$
Investment per job (N$/job)	914,145 N$/job	63,775 N$/job	95,312 N$/job

green scheme. We estimated that the construction of one ferrocement tank requires a team of one skilled and ten unskilled workers and takes 12 days. Calculating with 250 annual working days it finds that 770 tank builders (70 teams) can construct 21,875 ferrocement rainwater harvesting tanks over a time span of 15 years. A further 10,938 jobs are created in the gardening sector, assuming that workload and income from the gardening with the water from one ferrocement tank is equivalent to one half day job. When creating 11,736 new jobs, 22,500 ponds and gardens can be constructed and cultivated. For this, 486 pond builders (54 teams) with one skilled and eight unskilled workers per team take nine days to construct 1 pond, resulting in 1,500 ponds per year and 22,500 ponds over a period of 15 years. Further 11,250 jobs are created to cultivate gardens, assuming that the workload and income from the gardening with the water from one pond is equivalent to a half day job.

The construction of 21,875 ferrocement rainwater harvesting tanks requires an investment of 747 million N$ resulting in an investment per job of 63,775 N$. The construction of 22,500 rainwater harvesting ponds requires an investment of 1,119 million N$, resulting in an investment per job of 95,312 N$. The income generated with this number of rainwater harvesting tanks and gardens through the sale of horticulture products is 25–111 million N$ per year. These ponds and gardens generate an annual income of 71–310 million N$ (subsistence and market garden variant, respectively). In contrast, the green scheme is expected to require a considerably higher investment of 10,741 Mio N$ creating the same number of jobs but requiring a significantly higher investment per job of 914,145 N$. Assuming the same crop schemes for the green scheme would result in an annually generated income of 3,150–5,264 million N$. However it has to be considered that in reality the green scheme is also producing maize and wheat so that the generated income will be considerably lower than estimated here.

In central-northern Namibia, investment costs for water infrastructure are extraordinary high, owing to the large water supply network (Heyns, 1995). In central-northern Namibia the sales price of grid water is currently around 8.3 N$/m^3, but this price is heavily subsidised. In contrast, we estimate that the full cost recovery price including infrastructure investment costs is between 10 and 15 N$/m^3. In comparison to this, the full cost recovery price of our proposed rainwater harvesting infrastructure (ferrocement rainwater harvesting tank) is 15 N$/m^3. Therefore, the costs per square meter of harvested rainwater are not higher than the cost of grid water.

4.5. Financing of rainwater harvesting facilities

Private financing of initial investment costs represents a problem for most micro-entrepreneurs and is the major limiting factor for the up-scaling of rainwater harvesting. Average annual household income in central-northern Namibia ranges from 26,788 N$ in the Oshikoto region to 45,708 N$ in the Oshana region (Republic of Namibia, 2006). In relation to this income level, tanks and gardens have high investment costs, while the maintenance costs of rainwater harvesting facilities are very low. Therefore, we propose other sources to finance infrastructure material investment costs.

The results of this study indicate that microcredits are not suitable to finance material costs of rainwater harvesting facilities. On the one hand, traditional microcredit loans are usually too small with too short repayment periods (up to 2 years) and are not compatible with the necessary medium- to long-term investment of over 6 years for investment sums of over 12,000 N$. On the other hand repayments for annual interest rates (currently 24–35% p.a. in Namibia) (Chitambo *et al.*, 2006) exceed annual garden revenues of the subsistence garden. However, if only garden construction costs have to be financed through a microcredit, the credit can be easily repaid within a reasonable time. For instance, a micro-entrepreneur could assume a microcredit for garden construction of 3,320 N$ (with tank) or 6,615 N$ (with pond) and then repay it within 1 or 2 years with the profits generated from gardening, having subtracted annual maintenance costs for rainwater harvesting and gardening (considering an interest rate of 24%). Annual tank and garden maintenance costs can be easily paid with annual revenues together constituting 21–52% of annual garden revenues in the case of the tank and 15–27% in the case of the pond. Based on these considerations, other sources of finance have to be identified to cover rainwater harvesting facility investment costs. Our suggestion for financing is summarised in Table 7.

5. Discussion

5.1. Proposed policy implications

Owing to the inability of many micro-entrepreneurs and poor households to finance rainwater harvesting and garden infrastructure investment costs privately, other financing solutions have to be found. International institutions such as the Organisation for Economic Co-operation and Development (OECD) and The World Bank are becoming aware of the financing issue and argue that it is unrealistic to base financial planning of water services on full cost recovery of investment costs (OECD, 2009; Banerjee *et al*., 2010). The OECD therefore adopted a pragmatic policy towards financing investment costs for water services by advocating the concept of sustainable cost recovery.

The concept of sustainable cost recovery entails securing and programming financial means from all sources available to the country in an appropriate combination. This includes tariffs to finance operation and maintenance costs as well as government (taxes) and donor (transfers) support to finance recurrent and investment costs. State support can be justified by the external public benefits from good water services as well as the need to make these services affordable to the poorest households (OECD, 2009). This is also applicable for investments for agricultural water infrastructure.

Many countries wrap their subsidy element into ‘soft’ loans to utilities or local authorities, which has the advantage of preserving the incentive to make efficient use of the money. While recovering operation and maintenance costs or even investment costs from tariffs is an important economic principle in most circumstances, using tariffs to recover full costs of water services, including investment and

Table 7. Financing a proposal for rainwater harvesting and gardening infrastructure.

Type of cost	Financing	Pay back
Material cost for rainwater harvesting infrastructure	Government-funded (with beneficiary contribution depending on poverty level)	No pay back
Material cost for garden	Micro-entrepreneur with microcredit	Tank: 2 years (market), 22 years (subsistence)[a] Pond: 1 year (market), 2 years (subsistence)[a]
Annual maintenance cost for rainwater harvesting infrastructure and garden	Micro-entrepreneur with revenues from gardening	O&M costs constitute: Tank: 21% (market) to 52% (subsistence) of annual revenues. Pond: 15% (market) to 27% (subsistence) of annual revenues

[a]Time to pay back microcredit considering the available profit after having subtracted operation and maintenance costs from annual revenues.

major rehabilitation, is unusual even in developed countries. In practice, in many countries the governments prefer to subsidise investment costs through taxation (OECD, 2009). Nonetheless, recovering the cost of providing service, at least for operation and maintenance, is a stated objective of water utilities around the world (Banerjee *et al*., 2010). Therefore, government could subsidise rainwater harvesting infrastructure investment costs. Beneficiary contribution of capital costs, for instance of 5–20% depending on beneficiary poverty level, could be considered in order to enhance ownership and sustainability. Then, local tank owners and farmers can finance garden investment costs and maintenance of tanks and gardens by assuming a microcredit and repay it with market sale of gardening products. In doing so, the government could give incentives for value added production, local job creation, improvement and extension of water infrastructure and regional development. Therefore this study recommends state-funded rainwater harvesting material costs.

Besides these financial aspects, current Namibian policy is also an important precondition for the further development of rainwater harvesting-based gardening. The FAO recognises agricultural growth involving smallholders, especially women, to be most effective in reducing extreme poverty and hunger when it increases returns to labour and generates employment for the poor (FAO *et al*., 2012). Historically, smallholders have proved to be key players in meeting food demand. Today, smallholders face considerable challenges, such as limited accessibility to markets, credit, information and resources. Yet, smallholders are capable of meeting these challenges, although they need an appropriate enabling environment in order to do so. Providing improved rural infrastructure such as roads, markets, storage facilities and communication services will reduce transaction costs, enable farmers to reach markets, contribute to a better conservation of products and provide the possibility to add value to products by, for example, processing food. Interventions to ensure land tenure and property rights security will encourage smallholders to invest in land improvements. Provision of education in rural areas is essential if smallholders are to participate in markets (FAO *et al*., 2012). Currently, Namibia has an extensive policy framework to foster food security (Werner, 2011).

With regard to irrigation, however, current policies focus on large-scale commercial production and do not specifically target small-scale food producers at the local level. Therefore, despite the political intention of improving household food security, the majority of poor households in rural areas cultivating less than 20 ha does not directly benefit from current political programmes (Werner, 2011). The proposed rainwater harvesting infrastructure is explicitly not intended to replace the large-scale agriculture plans of the Namibian government. Instead, it is intended to complement it by also addressing small-scale agriculture and local market production. Thus, Namibian and international experts (e.g. Dima *et al*., 2002; Werner, 2011) recommend a review of the current policy framework to provide more focus on micro- to small-scale food production (below 20 ha) and on appropriate technical support and advice in urban, peri-urban and rural areas. This policy review also needs to address institutional mandates and responsibilities in order to provide the appropriate regulation. Promotion of gardening and rainwater harvesting require a concerted campaign at all levels of government and the target population to explain the potential importance and benefits (Werner, 2011). To complement gardening activities, a working infrastructure will be necessary including extension and consulting services for gardening, plant protection and seed nurseries.

An example of financing rainwater harvesting infrastructures with grants is the South African policy 'Financial Assistance to Resource Poor Irrigation Farmers' of the South African Department of Water Affairs and Forestry (DWAF) published in 2004 as part of the National Water Act of 1998. South Africa and Namibia have a similar history of political and economic imbalance between different parts of the population. The South African DWAF aims to promote social and economic development in the country through the use of water in an equitable way. It acknowledges micro-scale vegetable farming, where an estimated 150,000 farmers produce food for millions of people, to be an important sector of rural farming in South Africa. It complements the top-down managed large irrigation schemes that are one of the biggest success stories in agricultural development in the country. The act provides financial assistance for the development of irrigated agriculture by providing resource-poor farmers with grants and subsidies for water supply infrastructure and assistance for water management committees. The grant serves to construct rainwater harvesting storage tanks for resource-poor farmers in rural areas, to serve family food production and other productive uses. The grants provides annually 425,500 €, sufficient to build around 1,000 rainwater harvesting tanks per year (DWAF, 2004). Through this programme, the South African DWAF aims to contribute to the achievement of the UN Millennium Development Goals in South Africa by reducing the number of households suffering from food insecurity (DWAF, 2004). A similar programme can be established in Namibia to reduce poverty especially in its northern regions which are also disadvantaged in terms of economic and agricultural development.

5.2. Transferability of results

Our research and previous studies revealed a broad range of benefits of rainwater harvesting in technical, economic, environmental and social terms. Existing challenges can be handled by training and educating the local population. The results of the cost–benefit analysis in this study showed that rainwater harvesting is a profitable activity with a positive NPV over the lifespan of the infrastructure when planting crops that achieve high local market prices and excluding material costs for the rainwater harvesting facility, while including maintenance and operation costs and garden material. It has to be considered that the result of cost–benefit analyses depends on the choice and quality of data input and often, as in our case, only limited data (e.g. prices and yields of only 1 year from 2003) or data not specific for the model region (e.g. length of growth season for semi-arid regions) are available.

The validity of the results of our cost–benefit calculation has two aspects: the specific data used from the literature are reliable and therefore our specific results are also reliable. However, owing to inter-annual variability of, for example, market prices or agricultural yields, the literature data used from 1 year has limited significance. Therefore, the results of the cost–benefit calculation can be considered as preliminary. In the following years further field data should be collected in order to refine the cost–benefit calculation and obtain a more representative result for central-northern Namibia. In reality, the cost–benefit ratio depends on the actual lifespan of the facilities which we determined according to the extensive experience of a Kenyan rainwater harvesting consultant who constructed more than a hundred rainwater harvesting facilities in Kenya and Uganda in low-tech areas with comparable conditions to central-northern Namibia. In addition, irrigation requirements were modelled which also depend on climatic and crop data input.

First monitoring results showed that local market prices are higher than assumed (according to Price Waterhouse Coopers, 2005) in the worst garden variant and therefore revenues might be underestimated. This indicates that the benefit might be closer to the best case garden variant with a positive cost–benefit ratio. In addition there is a high demand for agricultural products in local markets. Putting rainwater harvesting in the frame of current water and irrigation infrastructure in Namibia, the results of this study indicate that rainwater harvesting-based small-scale gardening has relative low investment costs per created job. Therefore, the invested funds in rainwater harvesting and small-scale gardens are very effective in creating new jobs.

The role of rainwater harvesting for the irrigation of small-scale gardens has not been sufficiently examined in Namibia. However, ground and roof rainwater harvesting is significant for regions with an annual precipitation of at least 300 mm (Gould & Nissen-Petersen, 2006), contrasting rainy and dry seasons and is suitable for rural as well as peri-urban areas. A constraint to an up-scaling in Namibia is the high material cost of steel mesh, cement and wood compared to the poor local income situation. In other African counties comparable rainwater harvesting tanks, that is, 30 m^3 ferrocement tanks, have similar costs to Namibia. In Asia, material costs are 60–80% lower (Li *et al*., 2000; Agarwal *et al*., 2001; Cruddas, 2007; Kariuki, 2012, personal communication). The reasons are the unavailability of cement and clean graded river sand in some parts of Africa and a lack of sufficient water for construction in others. In addition, many parts of Africa have lower and seasonal rainfall and impervious roofs are smaller in number and size. In particular, compared to typical household incomes rainwater harvesting tanks are more expensive in Africa than in Asia. Nevertheless, rainwater collection is becoming more widespread in Africa and in some parts rapid expansion has occurred in recent years, even though progress has been slower than in Southeast Asia (UNEP 2002). In Namibia, government subsidies are necessary to finance the water harvesting infrastructure. The advantage of these technologies is that they are low-tech, they can be constructed by local inhabitants themselves, they better integrate into the natural landscape and into social circumstances and necessary investments are significantly lower than for large-scale irrigation projects. The water buffering capacity of the rainwater harvesting facilities are a good adaptation to the increasing variability of precipitation caused by climate change. Therefore, rainwater harvesting for irrigating gardens has a great future.

6. Conclusion

This study has shown that rainwater harvesting for the irrigation of small-scale gardens and the associated capacity development measures provide a wide range of benefits. Water harvesting and its productive use for horticulture is one key in reaching the poor in peri-urban and rural areas as the decentralised infrastructure provides them with direct access to means of production and allows them to improve their daily meals and their income in order to overcome poverty. In addition, rainwater harvesting is an effective adaptation strategy to climate change and climatic variability. Yet, the potential of rainwater harvesting in combination with gardening has not been developed in Namibia so far. To achieve broader benefits for the regional economy, investments in infrastructure and an adequate policy framework are needed. Owing to the high material costs in Namibia compared to low household incomes, subsidies are necessary to finance the water harvesting infrastructure. We recommend government funding of the rainwater harvesting infrastructure and private finance of garden and maintenance costs. The adoption of rainwater harvesting in Namibia's water policy framework would improve water access for communities in rural areas. Then, rainwater harvesting is a valuable contribution to reach Namibia's Vision 2030 and the Millennium Development Goals.

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