Indigenous knowledge as decision support tool in rainwater harvesting

S. Tumbo

Physics and Chemistry of the Earth, Parts A/B/C

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Physics and Chemistry of the Earth 30 (2005) 792–798

PHYSICS and CHEMISTRY of the EARTH

www.elsevier.com/locate/pce

Indigenous knowledge as decision support tool in rainwater harvesting

B.P. Mbilinyi [a,*], S.D. Tumbo [a], H.F. Mahoo [a], E.M. Senkondo [a], N. Hatibu [b]

[a] *Soil Water Management Research Group, Sokoine University of Agriculture, Tanzania*
[b] *Soil and Water Management Research Network (SWMnet) of ASARECA, Nairobi, Kenya*

Accepted 15 August 2005

Abstract

Rainfall patterns in semi-arid areas are typically highly variable, both spatially and temporally. As a result, people who rely completely on rainwater for their survival have over the centuries developed indigenous knowledge/techniques to harvest rainwater. These traditional water-harvesting systems have been sustainable for centuries. The reason for this is that they are compatible with local lifestyles, local institutional patterns and local social systems. In order to develop sustainable strategies, it is therefore important to take into account of, and learn from, what local people already know and do, and to build on this. This paper explores how indigenous knowledge is used by farmers in the Makanya catchment, Kilimanjaro region, Tanzania to identify potential sites for rainwater harvesting (RWH). The paper draws on participatory research methods including focus group discussions, key informant interviews, field visits and participatory workshops. Initial findings indicate that farmers do hold a substantial amount of knowledge about the resources around them. As there are spatially typical aspects to indigenous knowledge, it could be extrapolated over a wider geographic extent. From the preliminary findings, it is being recommended that geographic information system (GIS) could be an important tool to collect and upscale the utility of diverse indigenous knowledge in the decision-making process.

Keywords: Rainwater harvesting; Indigenous knowledge; Agriculture; Makanya catchment; Tanzania

1. Introduction

On the basis of the amount and distribution of rainfall, more than 50% of mainland Tanzania can be categorized as semi-arid (De Pauw, 1984; LRDC, 1987). Rainfall in these areas is highly variable both spatially and temporally. A large amount of the total annual rainfall is often received in one or a few high intensity storms. As a result, crop and livestock production under such conditions remains vulnerable to the adequacy, reliability and timeliness of rainfall. A number of studies have shown that the yield and reliability of agricultural production in the semi-arid areas can be significantly improved with rainwater harvesting (SWMRG, 2001; Falkenmark et al., 2001). In recognition of the potential of RWH to improve water availability and land productivity, efforts are being made to promote the use of the technology in Tanzania. For example, RWH is now a key element of the Agricultural Sector Development Strategy (URT, 2001).

RWH does not, however, constitute a new technology. People who rely completely on rainwater for their survival have over the centuries developed indigenous techniques to harvest rainwater. Small dams and runoff control means for agricultural purposes can be traced back to early history. The first water harvesting techniques are believed to have originated in Iraq over 5000 years ago (Falkenmark et al., 2001). In Tanzania, experience with RWH has a long history. Individual communities have over the centuries developed traditional water harvesting techniques which include among others, the excavated bunded basins locally called *Majaluba* for rice production in the Lake Zone,

* Corresponding author.
E-mail address: mbly_sua@yahoo.com (B.P. Mbilinyi).

1474-7065/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pce.2005.08.022

raised broad basins locally called *Vinyungu* in Iringa region and water storage structures locally called *ndiva* in Kilimanjaro region. These interventions are aimed at improving water availability for crop production. The concept of "*Mashamba ya mbuga*" where by farmers grow high water demanding crops in the lower parts of a landscape using rainwater from the surrounding high grounds has been practised for millennia in semi-arid areas of Tanzania. These traditional rainwater-harvesting systems have been perfectly sustainable for many years. The reason for this is that they are compatible with local lifestyles, local institutional patterns and local social systems. In order to develop sustainable RWH strategies it is therefore important to take into account of, and learn from, what local people already know and do, and to build on this.

Although more and more planners, policy makers, extension workers, development practitioners and researchers have come to realize the potential of indigenous knowledge (IK), it remains a neglected resource. A key reason for this is the lack of guidelines for recording and applying IK, particularly over a wider geographic extent. This creates an implicit danger that IK may become extinct.

This paper therefore attempts to deepen the scholarly understanding of the role of indigenous knowledge in RWH. In this paper, indigenous RWH technologies in the Makanya catchment, Kilimanjaro region, Tanzania are discussed and how indigenous knowledge is used by farmers to identify potential sites for different RWH is explored.

1.1. Need for understanding indigenous knowledge

Indigenous knowledge, also referred to as "traditional" or "local" knowledge, is the knowledge that people in a given culture or society have developed over time, and continue to develop. It is a body of knowledge based on experience that has often been communicated through "oral traditions" and learned through family members and generations, often tested over centuries of use, and adapted to local culture and environment. IK is not confined to tribal groups or the original inhabitants of an area. It is not even confined to rural people. Rather, any community possesses indigenous knowledge: rural and urban, settled and nomadic, original inhabitants and migrants.

According to Warren and Rajasekaran (1993), IK is a valuable national resource because:

(i) It includes practical concepts that can be used to facilitate communication among people coming from different backgrounds such as agricultural researchers and extension workers.
(ii) It helps to assure that the end users of specific agricultural development projects are involved in developing technologies appropriate to their needs.
(iii) It forms the basis for decision making, which is operationalized through indigenous organizations, and it provides the foundation for local innovations and experimentation.
(iv) It is cost-effective since it builds on local development efforts, enhancing sustainability and capacity building.
(v) IK systems can play an important facilitating role in establishing a dialogue between rural populations and development workers.

Indigenous knowledge has now been recognized and accepted as a vital knowledge source (Chimaraoke et al., 2003). This recognition is directly related to the growing realization that locally generated knowledge can be used to change and improve, for example, agriculture and natural resource management. Greater efforts therefore should be undertaken to strengthen the capacity of local people to develop their own knowledge base and to develop methodologies to promote activities at the interface of scientific disciplines and indigenous knowledge.

In the study area, IK is being used, among others, to guide development of RWH systems such as water storage structures and runoff diversion canals. Since these RWH systems have been developed locally, they are therefore considered as indigenous technologies.

1.2. Overview of rainwater-harvesting systems

In the broad sense, RWH is the process of concentrating, collecting and storing rainwater for different uses at a later time in the same area where the rain falls, or in another area during the same or later time (Hatibu and Mahoo, 2000). The term RWH describes a wide range of techniques which collect rainfall runoff for different uses, by linking a runoff-producing area with a separate runoff-receiving area (Young et al., 2002). RWH systems are typically classified into three categories based on the size of the runoff-producing area.

The first category of RWH system is on-farm systems or in situ RWH. This is the capturing of rainfall where it falls. The system is accompanied by cultural practices that ensure that crops make the most effective use of the scarce water. It is sometimes called water conservation and is basically the prevention of net runoff from a given cropped area by retaining rainwater and prolonging the time for infiltration. Essentially, it all includes conventional approaches to soil and water conservation, designed to enhance infiltration of rainwater into the soil. Examples of in situ RWH techniques include deep tillage, dry seeding, mixed cropping, ridges and borders, terraces ("*fanya juu*" and "*fanya chini*") and trash lines.

Another category of RWH system is a micro-catchment system, that involves a distinct division of a runoff-generating catchment area (CA), and a cultivated basin (CB) where the runoff is concentrated, stored and productively used by plants. The CA and CB are adjacent to each other (Gowing et al., 1999). This system is used mainly for growing medium water demanding crops such as maize, sorghum, groundnuts and millet. The techniques of RWH in this system include pitting, strip catchment tillage, contour bunds, semi-circular bunds and charco dams locally known as *lambo* in Kilimanjaro region.

The third category is macro-catchment RWH which characterized by large CA's. The CA area for these systems are located outside the cropped area, where individual farmers have little or no control over them. The systems include intermediate components for collecting, transferring and storing runoff. According to Gowing et al. (1999), such systems are difficult to differentiate from conventional irrigation systems, but it is referred to as RWH as long as the harvested water is not available beyond the rainy season. Water storage structures locally known as *ndiva* in Kilimanjaro region and "*Mashamba ya mbuga*" whereby farmers grow crops in the lower parts of a landscape using rainwater from the surrounding high grounds are examples of indigenous macro-catchment RWH systems.

In effect, the three categories show that the classification of RWH for crop production provides a continuum ranging from conventional soil and water conservation, at one end to irrigation at the other end. Furthermore, most of the examples in the three categories are indigenous RWH technologies developed by individual communities over the centuries to improve water availability for different uses including crop and livestock production. This shows that indigenous RWH technologies do occupy the entire range of RWH system, i.e. from in situ to macro-catchment system.

2. Methodology

2.1. The study area

The study was carried out in the Makanya catchment (approximately 300 Km^2) in the Western Lowlands of same district, Kilimanjaro region, Tanzania (Fig. 3). The catchment runs from the peaks of the South Pare Mountains westward to the Pangani River. The lowland part of the watershed is 500–700 m above mean sea level while the upper part reaches 2462 m above mean sea level.

The annual rainfall in the lower zone of the catchment is too low to support agricultural production without water management interventions. Mean annual precipitation ranges between 250 and 400 mm, falling in two seasons: short rains (*Vuli*) between November and January and long rains (*Masika*) between March and May. Agricultural production in this zone is only possible through RWH using supplementary water mainly from ephemeral flows during the rainy season. The rains fall mostly in the upper zone of the catchment as heavy showers which produce large runoff volumes (SWMRG, 2001). The runoff flows downstream where it is diverted to farms through canals. The storms are, however, very few and far between. According to key informants from Makanya village, the storms normally occur three times during the short rainy season. In November they last for one to three days while those in December can last up to seven days. Sometimes manageable floods occur in January too. During long rains, big storms occur three to four times. The key informants further mentioned that storms that occur during the short rains are bigger and more reliable than those during long rains.

The analysis of rainfall in the Makanya upper catchment showed that average monthly rainfall during short rains (October–December) is higher than during long rains (March–May) (Fig. 1). The higher amount during short rains is caused by fewer but bigger rainfall events as supported by daily rainfalls shown in Fig. 2. These results support farmers' observations that storms during short rains are bigger and more reliable than those during long rains.

Dry spells are very common in the area, even during the long rainy season. The most disastrous dry spells are those which occur in January and February when the maize crop is tasseling. Farmers lament that "just one more storm would have been sufficient to realize a good crop". This is why RWH is very important in the area as RWH mitigates the risks of intra-seasonal dry spells by bridging the

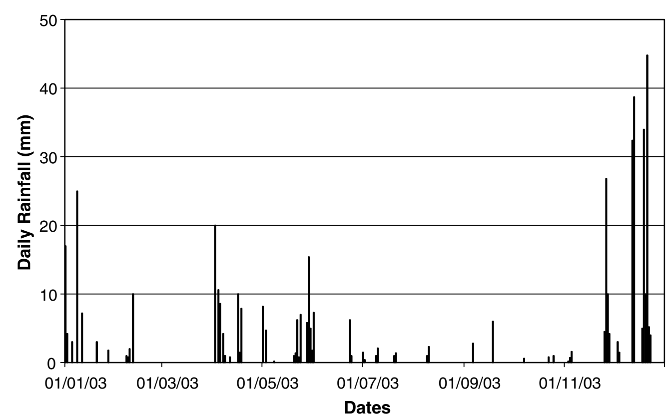

Fig. 1. Daily rainfall in 2003 showing long rains (March–May) being lower than short rains (October–December) in upper part of the Makanya catchment. Source: Suji weather station.

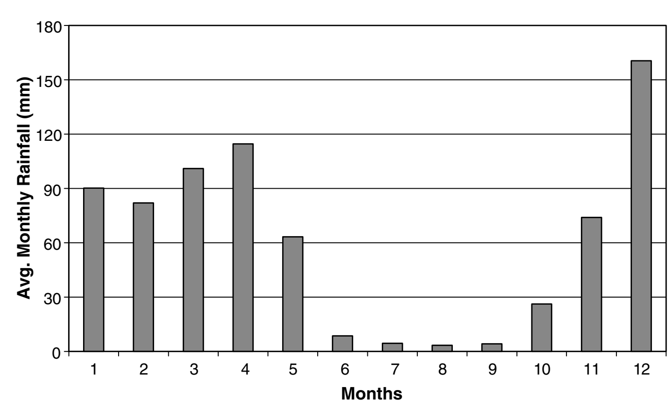

Fig. 2. Mean monthly rainfall in upper part of the Makanya catchment (1992–2003). Source: Suji weather station.

gap between rainfall events, by providing supplemental water of this critical period of the crop's growth.

2.2. Study approach and data collection

A preliminary survey, using rapid rural appraisal (RRA) as a tool and a review of previous research documents were conducted to guide identification of study villages and then villagers within the villages. Three villages with a background on RWH activities located in the Makanya catchment, were purposely selected to represent major landscape positions/toposequence in the catchment. These focused on runoff producing area (highlands), runon area (middle slope), and runoff receiving area (lowlands). This was done in order to capture variations in RWH technologies and activities along the toposequence. The villages are Makanya (lowlands), Mwembe (middle part), and Tae (upper part) (Fig. 3).

To capture the variability in indigenous knowledge among the villagers in the study villages, members from each social group were sampled. The sample households were drawn from the village registers. For each village, the sample included about 10% of the total villagers practicing RWH. The selection was random within each category. A total of 100 farmers from each study village were involved.

Following the RRA preliminary analysis, a combined use of different data collection methods was used to provide an improved understanding of the variability of indigenous knowledge related to RWH in the study area. The following methods were employed:

2.2.1. Participatory rural appraisal

In order to make use of the knowledge acquired by local communities and to understand social circumstances relating to RWH, PRA tools were used. These included focus group discussions, observations, and open-ended interviews of key informants. The interview was complemented by focus group discussions to explore further the existing indigenous RWH technologies in the area and IK used to

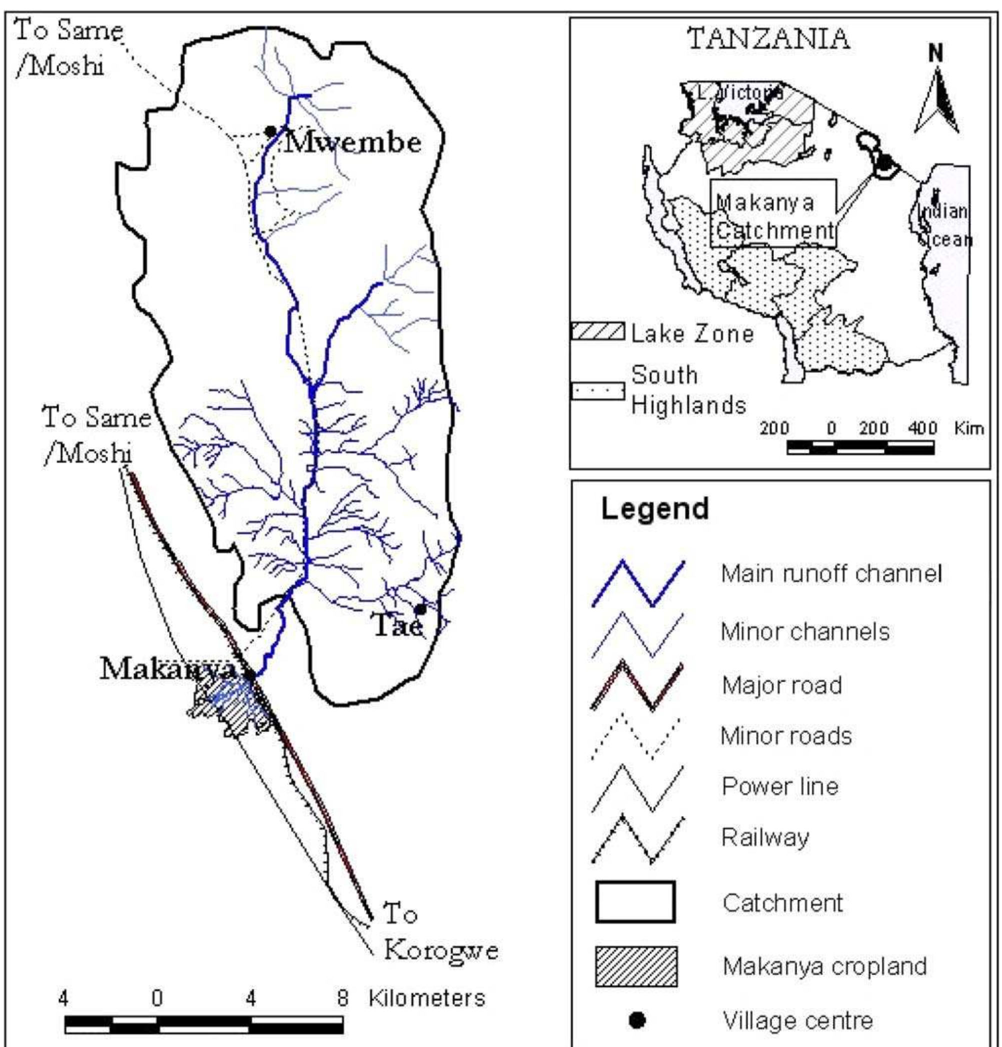

Fig. 3. The Makanya catchment showing the location of study villages (Makanya, Mwembe, and Tae).

identify potential sites for each technology. The size of each group was no larger than 15 people. The survey targeted farmers and livestock keepers; village organizations related to RWH (i.e. water user groups), extension officers; the district planner; district agricultural and livestock officers; and NGOs actively involved in RWH. In the interviews, issues emerged from the discussion was used to guide the development of a structured questionnaire.

2.2.2. Questionnaire survey

A questionnaire was administered to quantify data that were collected during the PRA exercise. The intended respondents were heads of households. The questionnaires and PRA were designed to gather the following information related to RWH:

(a) Indigenous knowledge. This included technologies and practices, information, tools/equipments, materials and human resources (e.g. specialists such as blacksmiths, local organizations such as kinship groups, councils of elders, or groups that share and exchange labour).
(b) Experiences of local experts, including extension workers and NGO staffs, on land characteristics and other factors known to be critical for RWH.

2.2.3. Participatory workshop

In the last phase of the study, a oneday workshop was organized to inform and discuss preliminary research findings on existing RWH technologies in the study area and indicators used to identify them with stakeholders. A total of 16 participants, including researchers; district and village extension officers; the Local Councillor from same district; the Coordinator from SAIPRO (an NGO from same district) and farmers from Western Pare Lowlands and Maswa District, Shinyanga region (Lake Zones), participated in this workshop. The workshop participants were selected to represent different categories of stakeholders in RWH. It is also important to note that the participants were drawn from different zones/regions of Tanzania. This was purposely done to get views from a wider geographic extent.

3. Results and discussion

3.1. Existing indigenous RWH technologies

Several indigenous RWH technologies exist in the study area. The technologies range from in situ RWH systems, such as tillage, runoff basins and canals/ditches, to macrocatchment systems involving use of diversion canals. It was also observed that, these technologies are rarely found individually in the field, but rather a combination of two or more of them. Table 1 shows the ranking of most commonly used combinations of technologies in the area.

From Table 1, it is clear that RWH systems are used variably within and among the three zones of the toposequence. For example, use of storage structures or *ndiva* is common in the upstream villages. The reason behind this could be that, in the upper stream villages, the runoff flows with relatively high speed which then requires controlled structures before it can easily be managed and utilized by farmers in their fields. Likewise, the use of terraces is common in the highland villages in order to control soil erosion. Variability within a zone is more associated with the location of a field in relation to water sources. Fields located far from water sources have more tense combinations of in situ techniques. The techniques are designed to enhance infiltration of rainwater into the soil.

3.2. Factors guiding selection of potential sites for RWH structures

The choice of the kind of RWH that one can adopt is a multi criteria endeavour. Box 1 shows factors considered by farmers in selecting potential sites for RWH as described by key informants. On the other hand, Box 2 shows some of the IK used for locating RWH structures. A more detailed discussion on the IK is provided for the following four technologies: small water reservoir for crop

Table 1
Highly ranked combinations of indigenous RWH systems in the study area

Location on toposequence	RWH systems for crop production		
	1st Rank	2nd Rank	3rd Rank
Upper zone	Large planting pits, deep tillage, dry seeding, mixed cropping	Large planting pits, deep tillage, tree, banana and coffee, trash line	*Ndiva*[a], diversion canals, terrace, deep tillage, strip cropping
Middle zone	Ephemeral river, diversion canal, large planting pits, deep tillage, dry seeding, mixed crop	Ephemeral river, diversion canal, *ndiva*, canals, "*fanya juu*" terraces, deep tillage	Ephemeral river, diversion canal, *ndiva*, canals, "*fanya chini*" terraces, deep tillage
Lower zone	Ephemeral river, diversion canals, borders, deep tillage, dry seeding	Ephemeral river, diversion canals, deep tillage, mixed crops, dry seeding	Ephemeral river, diversion canals, deep tillage, dry seeding

It is important to note that charco dams, locally known as *lambo*, are very important RWH technology in the lower zone. The technology does not appear in the table because it is used to store runoff water for livestock.

[a] *Ndiva* is a structure used to store harvested rainwater for crop production. It is usually constructed manually using very simple tools such as hand hoes, axes and spades. The outlet gates, locally known as *igorino*, are made from materials that do not decay easily in water. These are made from special tree species and animal hide.

production (*ndiva)*, charco dam (*lambo),* diversion canal (*sasi)* and ridges, representing storage structures, conveyance system and in situ RWH system, respectively.

Box 1: Factors guiding site selection for RWH structures

Water storage structure for crop production (*ndiva*)
- Clay soils
- Sloping terrain
- Near water sources e.g. stream
- Shallow water table

Charco dam (*lambo*)
- Soils with good water holding capacity
- Flat area
- Far from settlement
- Presence of conveyance system
- Non-saline soils

Diversion canal (*sasi*)
- Hard stable soils
- Gentle slope
- No rocks

Ridges and border
- Slopes
- Access to runoff (location of the farm)
- Soil type

Box 2: Indigenous Knowledge on potential sites for RWH

- Areas with high moisture content indicate shallow water table and best areas for water storage reservoirs.
- Heavy and stable soils are suitable areas for routing canals.
- Clay soils have high water holding capacity and therefore the best soils for water storage reservoirs.
- Best locations for charco dam are those where warthogs dig their ponds in search of water.
- Flat areas adjacent to a gently slope is the best for charco dams.

3.2.1. Small water reservoir (ndiva)

Sites with potential for constructing *ndiva* are assessed by soil properties, nature of terrain, proximity to streams or ephemeral streams and depth of water table.

According to farmers, clay soils are the best for *ndiva* as they have high water retention capacity and allow relatively low seepage and percolation rates. Since the *ndiva* is a storage tank, it has to be close to the source of water recharge, particularly streams or ephemeral flows. However, the *ndiva* should not be positioned perpendicular to the stream as it can be washed out by heavy flows. It should rather be positioned a little away from the stream or ephemeral flow and be supplied with a conveyance system locally called *sasi*. Sloping areas are the more preferred type of terrain for *ndiva* as water can easily enter and exit by gravity. Another important factor that farmers consider before deciding where to locate *ndiva* is the depth of water table. Areas with high water table are considered to be the best. This is because, apart from recharge from streams and ephemeral flows, *ndiva* located in such an environment benefits from underground recharge. Farmers identify areas with high water table by looking at moisture content of the soils. Such places always look wet and a concluding indicator of high water table is the presence of springs, particularly during the rainy seasons.

3.2.2. Charco dam (lambo)

Charco dams are used to store runoff water mainly for livestock. Farmers identify potential sites for charco dams by examining topography and soil properties. Usually charco dams are constructed in flat areas adjacent to gently sloped areas (catchment) to ease runoff collection. Soils with high water retention capacity are well suited for charco dams. Such soils should also be non-cracking. Mineral contents are also considered during selection of sites for charco dams. Soils with salty minerals are not suitable. It was learnt during key informant interviews that pastoralists prefer to locate their charco dams in places where warthogs dig their ponds in search of water. It is believed that such places supply good amounts of water with no salinity problems. Charco dams are constructed far away from settlement areas. This is to avoid livestock destroying crop and field structures on their way to and from the charco dams, thus avoiding conflict between livestock keepers and crop producers.

3.2.3. Runoff canals (sasi)

Sasi are canals that either tap runoff from the stream or ephemeral flows and direct it into the *ndiva*, the charco dam or the cropped area. According to key informants, farmers consider two factors in identifying potential location for *sasi*; i.e. are soil properties and topography. Heavy and stable soils are suitable because they are less erodible compared to light and fragile soils. Sometimes, farmers have to ferry clay soils some distance to line canals in areas that are repeatedly breached. *Sasi* need gentle slopes for reducing speed and erosivity power of runoff. It is common to find a *sasi* with several meanders, several times to maintain a constant gradient and runoff speed. It was further reported that areas with big stones are not suitable for *sasi*. Stones do not only make digging of *sasi* tedious, but also increase water losses through percolation.

3.2.4. Ridges and borders

According to key informants, areas suitable for construction of the ridges and borders are those with medium to low slope. Areas with higher slopes require more labour. Another important factor is the access to runoff, which is a function of location of the farm along the toposequence. In areas with high slopes, the upstream boarders have an easy access to runoff compared to downstream areas. Ridges and borders are suitable for soils with high water holding capacity. Sandy soils are not suitable for ridges and borders.

During the participatory workshop, the local indicators, described above, for identifying potential sites for different RWH techniques were discussed and compared with indicators used by farmers from Maswa District in the Lake Zone and Mbeya region in the Southern Highlands of Tanzania to assess their wider applicability. The discussion revealed that, with minor differences, most of the indicators are similar. The only major difference was that in the Maswa District, in addition to the afore mentioned indicators, specific vegetation types are used to indicate presence of water, and hence areas good for charco dams. It was clear from the discussion that most of the IK used by farmers to identify potential sites for different RWH structures is based on biophysical parameters such as topography, soil type, distance from water sources and vegetation. Due to the spatial nature of such aspects of IK, geographic information system (GIS) can assist in the collection and upscaling of the utility of diverse IK in the decision-making process. Such applications have been reported by various researchers. For example, Tabor and Hutchinson (1994) and Gonzalez (1995) described the advantages of using GIS to document indigenous knowledge. Lawas and Luning (1996) have documented GIS applications at the local level, while Oweis et al. (2001) has provided interesting example of the potential power of GIS and remote sensing for mapping potential sites for RWH. Moreover, GIS complement the indigenous knowledge systems traditionally used to store and transfer knowledge and information. We also expect to use GIS to capture and upscale the identified IK in the next phases of the study.

4. Conclusions

From the results and discussions, the following conclusions can be drawn:

(i) Farmers do hold a substantial amount of knowledge on RWH systems and identification of potential sites for different RWH systems. This locally generated knowledge could be used to improve agricultural production in semi-arid areas.
(ii) It is rare to find a single technology on a farm but rather multiple technologies are being used simultaneously. There is therefore a need to identify integrated RWH systems. Most of the integrated RWH technologies are also soil and water management systems. They can therefore be referred as integrated soil and water management systems.
(iii) Although there could be variations of IK from one geographic area to another, most is based on biophysical factors, including topography, soil type and distance from water sources. These factors could be extrapolated over a wider geographic extent using GIS techniques.

Acknowledgment

This study was supported by the Water Research Fund for Southern Africa (WARFSA).

References

Chimaraoke, O.I., Ugai, G.A., Ukwayi, J.K., 2003. Indigenous knowledge and communal conflict resolution: evidence from Nigeria. INDILINGA—African Journal of Indigenous Knowledge Systems 2 (2).

De Pauw, E., 1984. Soils, physiography and agroecological zones of Tanzania. Crop Monitoring and Early Warning Systems Project, FAO and GoT, Dar es salaam.

Falkenmark, M., Fox, P., Persson, G., Rockstroem, J., 2001. Water harvesting for upgrading of rainfed agriculture. Problem Analysis and Research Needs. SIWI Report II. Stockholm International Water Institute, Sweden.

Gonzalez, R.M., 1995. KBS, GIS and documenting indigenous knowledge. Indigenous Knowledge and Development Monitor 3 (1).

Gowing, J.W., Mahoo, H., Mzirai, O.B., Hatibu, N., 1999. Review of rainwater harvesting techniques and evidence for their use in semi-arid Tanzania. Tanzania Journal of Agriculture Science 2 (2), 171–180.

Hatibu, N., Mahoo, H., 2000. Rainwater Harvesting for Natural Resources Management. A planning guide for Tanzania. RELMA, Nairobi, p. 144.

Lawas, C.M., Luning, H.A., 1996. Farmers knowledge and GIS. Indigenous Knowledge and Development Monitor 4 (1).

Oweis, T., Prinz, D., Hachum, A., 2001. Water harvesting: indigenous knowledge for the future of the drier environments. International Center for Agricultural Research in Dry Areas (ICARDA), Aleppo, Syria, p. 40.

Soil Water Management Research Group (SWMRG), 2001. Assessment of Rainwater Harvesting Demand and Efficacy. Sokoine University of Agriculture. Unpublished NRSP Project R7888 report.

Tabor, J.A., Hutchinson, C., 1994. Using indigenous knowledge, remote sensing and GIS for sustainable development. Indigenous Knowledge and Development Monitor 2 (1).

United Republic of Tanzania (URT), 2001. Agricultural Sector Development Strategy. Ministry of Agriculture, Dares Salaam.

Warren, D.M., Rajasekaran, B., 1993. Putting local knowledge to good use. International Agricultural Development 13 (4), 8–10.

Young, M.D., Gowing, J.W., Wyseure, G.C., Hatibu, N., 2002. Parchedthirst: development and validation of a process-based model of rainwater harvesting. Agricultural water management 55, 121–140.