Identification of Suitable Indices for Identification of Potential Sites for Rainwater Harvesting

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Abstract

Although indigenous and scientific knowledge for locating potential sites for water harvesting technologies do exist, a simple and integrated tool to assist farmers' support agencies, is missing. A geographic information system (GIS)-based decision support system (DSS) can be a valuable tool for such a task. However, key to such DSS are the factors and their suitability levels, which are not well developed. This study therefore focused on the development of suitability levels for most important factors/parameters for identification of such sites. The factors included rainfall, soil texture, soil depth, drainage, topography and land use or cover. Specific suitability levels were derived from analysis of existing RWH technologies in Makanya river catchment. Results showed that suitability levels of factors differ with different RWH technologies. Suitable areas for ndiva is on steep slopes (18^o-30^o) with clay soils, stone terraces is on moderately steep slopes (10^o – 18^o) with sandy clay loam soils, bench terraces (5^o-18^o slopes, clay or silt clay soils) and "boda" (2^o-5^o slopes, slit clay or clay soils). It was also found that ndiva, "boda", stone terrace and bench terrace are located at a distance within 125m from cropland. Testing of the developed parameters using ArcView-based DSS framework showed that 81.4% RWH technologies were located in the very high and high suitability levels, indicating the usefulness of the developed parameters and their suitability levels.

Keywords: Rainwater harvesting technologies, Suitability levels, Indigenous knowledge.

Introduction

Rainwater harvesting (RWH) is the process of collecting runoff from one area (normally uncropped) for various uses such as for domestic and livestock, crop production, fodder and trees and to a lesser extent water supply for fish and duck ponds (Pacey and Cullis, 1986; Critchley *et al.*, 1991; Mwakalila, 1992; Lameck, 1994). RWH technologies can be categorised under three broad classes namely; in-situ, micro-catchment and macro-catchment RWH. However, the classification is further complicated by the fact that a number of RWH technologies and systems are in most cases integrated or combined by land users. For example, some fields under conservation tillage, which is one of the rainwater harvesting techniques, can also incorporate runoff harvesting from external catchments or from storage reservoirs. Some of the common RWH technologies include terraces (stone and bench) and boda, which are basically small basins (about 2m x 2m), built around a small cropping area to retain harvested water in that location to infiltrate. Another important RWH technology in the Makanya catchment is a storage reservoir known as ndiva. Terraces and boda are basically in-situ RWH technologies (Mbilinyi *et al.*, 2005).

Indigenous knowledge (IK) has been used for decades for developing RWH technologies which in turn have proved to be sustainable. The reason for this is that they are compatible with local lifestyles, local institutional patterns and local social systems (Mbilinyi *et al.*, 2005). Researchers, planners, agricultural extension workers and development practitioners have realized that it is important to build on what local people know, i.e. IK, in order to develop sustainable RWH strategies.

Prinz *et al.* (1998) found that the most important parameters to be considered in identifying potential sites for water harvesting are rainfall, soil texture and depth, topography, drainage conditions, and land use or vegetation cover. Therefore, understanding and quantification of factors, which influence location of RWH systems is essential.

Most of the decisions on where to locate the RWH systems are spatial. Different layers of important factors will need to be combined to determine their suitability. Normally, multi-criteria evaluation techniques are used in combining the different factors. In multi-criteria evaluation, suitability levels/values of each factor and their relative importance weights of the different factors need to be established. Suitability levels refer to the degree to which a certain value in a given factor influences the location of a RWH technology. For example, very steep slopes will not be suitable areas for bench terraces compared to gentle slopes. Hence low values of suitability will be assigned for steep slopes compared to mild slopes.

Some RWH techniques are site-specific and sometimes indigenous knowledge exists in those sites, therefore, there is a need for an in depth study at such locations with the aim of establishing a clear relationship between the respective factors. The Makanya watershed in Tanzania has relatively high adoption of various types of RWH technologies (Pachpute *et al.*, 2009) which makes it an ideal site for studying the relationship between the various factors and the existing technologies.

Furthermore, studies into socio-economic factors that influence adoption of different RWH technologies in the Makanya catchment have been conducted (Masuki *et al.*, 2005). Senkondo *et al.* (1998 and 1999) found that farm size, number of family members working in the farm, experience in farming and extent of knowledge in RWH techniques as being significant adoption factors. However, number of plots and sex of household was also found to affect adoption of RWH. The study by Masuki *et al.* (2005) found that group networking, years spent in formal education, age of respondent, location and agricultural information pathways as being major determinants of intensity of adoption at farm-level. Therefore, significant work has been done on socio-economic factors and little has been done to investigate bio-physical factors. Therefore, the aim of this study was to identify and characterize the determining biophysical factors for locating potential sites for RWH technologies.

Factors for identification of potential sites for RWH

Rainfall

The availability of rainfall data series in space and time is important for rainfall-runoff processes and also for determination of available soil moisture (Prinz and Singh, 2000). A study done by Prinz (1996) indicated that in semi - arid areas, annual precipitations for different forms of water harvesting range from 100 – 700 mm/year and the minimum precipitation for practising rainwater harvesting is around 200 mm/ year. Thus <200 mm/year is not suitable, 200 – 300 mm/year is marginally suitable, 300 – 400 mm/year is moderately suitable, 500 – 600 mm/year is suitable and greater than 600 mm/ year is highly suitable.

Soil texture

Texture is an important soil characteristic because it will, to some extent, determine water intake rates (infiltration) and water storage in the soil (Donahue *et al.*, 1990). According to White (1987), fine and medium textured soils are generally the more desirable for RWH because of their superior retention of nutrient and water. Soils with high percentage of silt and clay particles have higher water-holding capacity (Ball, 2001). Water holding capacity of a soil is a very important soil property in RWH systems (Ludovic, 2004).

Soil depth

Generally, the deeper the soil the higher is the water storage capacity and vice versa. Sites with deep soils are relatively suitable for location of in-situ RWH technologies than shallow ones as deep soils have higher capacity of storing the harvested runoff as well as providing a greater amount of total nutrients for plant growth (Moges, 2004).

Topography

The landforms along with slope gradient and relief intensity are other parameters influencing the type of water harvesting system (Prinz *et al.*, 1998). To ensure high runoff efficiency, the slope of a catchment should be as steep as possible. However, slopes of more than 5% are susceptible to high erosion rates. Where the catchment has slopes steeper than this, erosion control measures are a necessity (Hatibu and Mahoo, 2000).

Vegetation cover

Vegetation is another important parameter that affects the surface runoff. Studies in West Africa (Tauer and Humborg, 1992) have shown that an increase in the vegetation density results in a corresponding increase in interception losses, retention and infiltration rates which consequently decrease the volume of runoff. In general, cultivated lands are suitable for certain types of RWH technologies such as boda, whereas riverine vegetation are not suitable. Therefore, consideration of vegetation cover is important in deciding location of different types of RWH technologies.

Drainage patterns

The suitability of a cropping area for a water harvesting system depends on drainage density. Areas with high drainage density will rank higher in suitability compared to areas of low drainage (Prinz *et al.*, 1998). Water harvesting structures located at great distances from the river(s) have a much greater potential for water loss due to evaporation and seepage (Risinger and Turner, 2004). It therefore implies that water harvesting structures should be located closer to rivers. Bothale *at el.* (2002) observed that the water harvesting structures are preferred along streams at intervals of about 500 m on either side of the river (a buffer of 1 km is sufficient). The categorization for suitability purpose will have to be defined within 500 m from the river. At the same time, depending on the type of RWH technology for example ndiva and terraces, ndiva might be given a higher priority compared to terraces because the closer the ndiva is to the water source, the least distance water will have to travel.

It can be concluded that none of the above parameters can be used independently to identify potential sites for RWH technologies. Usually, a combination of all possible parameters is used to support the decision making process. Based on Mbilinyi *et al.* (2005) on the existence of IK in the area, this study used it to guide the locations that are suitable for RWH technologies. The characteristics of the locations of RWH technologies were then coded to provide the suitability levels and determine their relative important weights.

Materials and Methods

Study Area

Bangalala and Mwembe villages in Makanya watershed (Figure 1) were selected as sites for developing suitability indices. The sites were selected based on the intensiveness and diversity of RWH systems, which could assist in the assessment and identification of potential sites for RWH technologies for other locations with similar biophysical characteristics. Also, these two villages are located in the midlands of the watershed containing technologies found in the uplands but not in the lowlands and vice versa.

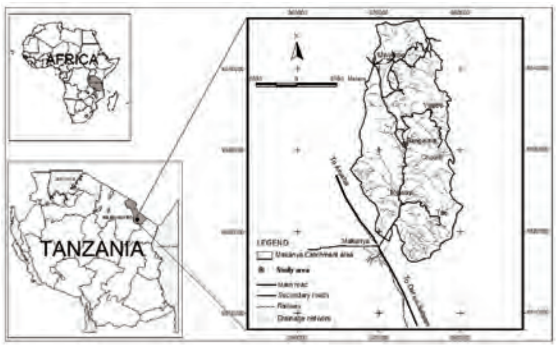

Figure 1: Map showing Makanya watershed in Same District, Northern Tanzania

The rainfall pattern in the study area is bimodal, with mean annual rainfall ranging from 400 – 700 mm (Mkiramwinyi, 2006). The short rains (vuli) start in November and extend to January. The long rains (Masika) start in March and extend to May. The study area is dominated by an undulating landscape. The terrain on the upper part is composed of steep rocky hills with slopes ranging from 18° to 52°. The altitude ranges between 830 m and 1042 m above mean sea level (amsl) with latitudes and longitudes as shown in Figure 1.

The catchment drains to Makanya River (Figure 1). The area is characterized by fairly uniform vegetation type of open bushland with scattered trees, woodlands and riverine vegetation. Open woodlands and bushland dominate the hilly slopes of the area (Pachpute *et al.*, 2009).

The catchment in general has high population density (300-400 people/km^2). The most dominant farming system is agro-pastoralism. Agriculture is practised in the form of mixed farming system where maize is intercropped with legume crops (beans, green grams, lablab bean). Apart from maize and legumes, others crops include bananas, sugarcane and vegetables. The total land area investigated is 805 ha for Bangalala village and 244 ha for Mwembe village. Thirty percent (30%) is cropped land in Bangalala village whereas cropped land. Discussion with crop agriculture extension staff revealed that the pasture land is not yet defined; therefore, the non-cropped land is used by livestock keepers for pasture.

Data Collection

The collected data, which focused on the most important parameters used in identifying potential sites for water harvesting, were soil texture, soil depth, topography, land use/cover, drainage pattern and rainfall. A total of five (5) ndiva, 14 stone terraces, 46 bench terraces and 75 boda were used in the study.

Soil texture and soil depth

At the beginning of the field survey, interpretation of aerial photographs from 1983 was carried out visually and stereoscopically. Landform, vegetation cover and drainage patterns were taken as key attributes for preparing the mapping units.

Free soil survey procedure was adopted in soil sampling (Dent and Young, 1981) at a scale of 1: 10,000 and an observation intensity of one observation per 140 m^2. Soil was described at each point by augering to 110 cm depth or to a limiting layer (where the soil depth was limited by stones underneath). Some soil profile pits were used to describe the soil. Soil colours were described using Munsell Soil Colour charts (Munsell Soil Colour Company, 1954). Surface stoniness, rock outcrops, topography, latitude, longitude and elevation were also observed and recorded using a post-processing differential GPS.

Soil textural classification was based upon the relative proportions of each of the three soil separates – sand, silt and clay and soil depths were categorised into different effective soil depth classes based on the criterion established by FAO (1990). The established textural name and depth classes were used in construction of soil depth and texture map using ArcView GIS software.

Topography

Differential GPS was used to record coordinates and elevations, at every 100 meters or less, along transect lines. The data were processed in a GIS environment to produce a contour map that was used to construct a Digital Elevation Model (DEM). Using the Surface Analysis menu, with the “derive slope” option, the slope map was produced. Slopes were grouped into five (5) classes based on their suitability level for each RWH technology: (1) highly suitable (2) suitable (3) moderately suitable (4) marginally suitable (5) not suitable.

Land use/cover

Visual and stereoscopic interpretations of the aerial photographs were carried out to extract different land uses/covers. The variation in the photo elements like tone, shape, size, pattern, texture, shadow, site and association was a key attribute for identifying land use/cover types namely open woodland, open bushland, open bushland with scattered trees, and cropland. Land use/cover types were categorized into five (5) suitability classes: (1) highly suitable for cropped areas (2) suitable for open bushlands (3) moderately suitable for open bushland with scattered trees (4) marginally suitable for open woodlands with bushlands, and (5) not suitable for riverine vegetation.

Rivers

Rivers were digitised directly from the topographic sheet 89/2 of 1988 at a scale of 1: 50,000. A buffer map showing different suitability areas in terms of distance from drainage patterns/streams, was then extracted from the drainage pattern using Arc View GIS software. Based on Bothale *et al.* (2002), the distances from the drainage pattern were categorized into the following suitability classes: 0 – 125 m (highly suitable), 125 – 250 m (suitable), 250 – 350 m (moderately suitable), 325 – 500 m (marginally suitable) and more than 500 m (not suitable).

Rainfall

The suitability levels for rainfall was determined based on data observed at Hassan Sisal Estate and Suji mission from year 1991 to 2002 seasons. These rainfall stations are about 7 km from the study area. Based on mean annual rainfall data obtained from these stations and information described by Prinz (1996), a rainfall map of suitability level ranging from moderately suitable to highly suitable (see sub-Section 2.1) was prepared using Arc View GIS software.

Determination of suitability levels for each of the factors/parameters

Suitability levels for each of the factors/parameters were categorized based on results of field survey and literature review (White, 1987; Prinz *et al.,* 1998; and Moges, 2004). The suitability levels were assigned a value on a scale of 1 to 9 (Diamond and Parteno, 2004). This ranking system was selected because it has been used in many studies (McGregor, 1998 cited in Diamond and Parteno, 2004) and it has been found to be a robust and reliable method (Store and Kangas, 2001 cited in Diamond and Parteno (2004).

Testing applicability of the suitability levels

The suitability levels were tested using ArcView-based Decision Support System (ADSS) framework for determining potential sites for rainwater harvesting as described in Mkiramwinyi (2006) and Mbilinyi *et al.* (2007). This framework uses the weighted overlay process also known as the multi-criteria evaluation (MCE). The MCE creates an output layer by combining the values in multiple input layers (Mkiramwinyi, 2006; Mbilinyi *et al.*, 2007). For each location, the cells in each input layer at that location are weighted and then different layers are overlaid to create the output layer. In this study, the input layers were rainfall, slope, soil texture, soil depth, drainage and land use/cover and the RWH technologies were ndiva, stone terraces, bench terraces and boda.

Results and Discussion

Determinant Factors and RWH Technologies

Slope

The results indicate that the highest proportion of ndiva (80%) were located on slopes ranging from 10° - 30°, while 53.7% of stone terraces were located on moderately steep slopes (10° - 18°). The highest proportion of bench terraces (41.3%) were located on slopes ranging from 10° - 18° and very few were located on slopes between 2° - 5°. Most of the boda were located on slopes ranging from 2° - 5° and very few on slopes between 18° - 30° (Table 1).

Table 2: Occurrence of RWH technologies on different soil depth

Soil depth (cm)	Stone terrace		Bench terrace		Boda	
	Freq	%	Freq	%	Freq	%
10-30	2	14.3	3	6.3	1	1.3
30-50	8	57.1	10	22.9	11	14.1
50-100	4	28.6	29	62.5	19	25.6
100-150	-	-	4	8.3	44	59.0
Total	14	100.0	46	100.0	75	100.0

Soil Depth

The results (Table 2) indicate that most of the stone terraces (57.1%) were located on soil depth ranging from 30 – 50 cm and none on depth >100 cm. Most of the stone terraces were located close to the water sources and associated with availability of stones. The same was observed by Hudson (1981). Most of the bench terraces (62.5%) were on moderately deep soils, whereas most of the boda (59%) were located on deep soil (100 – 150 cm).

Table 1: Occurrence of RWH technologies on different slope ranges

Slope (°)	Ndiva		Stone terrace		Bench terrace		Boda	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
2 – 5	-	-	1	7.1	3	6.5	45	60
5 – 10	1	20	4	28.6	15	32.6	21	28
10 – 18	2	40	5	53.7	19	41.3	7	9.3
18 – 30	2	40	4	28.6	9	19.6	2	2.7
Total	5	100	14	100	46	100	75	100

Table 3: Occurrence of RWH technologies on different soil texture

Soil texture	Ndiva		Stone terrace		Bench terrace		Boda	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Loamy sand	-	-	1	7	-	-	-	-
Sandy Loam	-	-	6	43	4	8	2	3
Sandy Clay Loam	1	20	4	29	5	10	6	8
Clay Loam	-	-	2	14	0		0	
Sandy Clay	-	-	1	7	7	15	4	5
Silty Clay	1	20	-	-	13	29	30	40
Clay	3	60	-	-	17	38	33	45
Total	5	100	14	100	46	100	75	100

Table 4: Occurrence of RWH technologies on different land cover/use

Land cover/use	Ndiva		Stone terrace		Bench terrace		Boda	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Cropland	3	60	12	86	35	76	42	56
Open Bushland	2	40	-	-	2	4.3	18	24
Open Bushland with scattered trees	-	-	-	-	9	19.7	5	6.7
Open woodland	-	-	2	14	-	-	9	12
Riverine vegetation	-	-	-	-	-	-	1	1.3
Total	5	100	14	100	46	100	75	100

Table 5: Relationship between RWH technologies and distance from drainage channels

Drainage (m)	Ndiva		Stone terrace		Bench terrace		Boda	
	Counts	%	Counts	%	Counts	%	Counts	%
0-125	2	40	8	57.1	27	58.7	24	32
125-250	2	40	6	42.9	18	39.1	36	48
250-350	1	20	-	-	1	2.2	13	17.3
350-500	-	-	-	-	-	-	2	2.7
Total	5	100	14	100	46	100	75	100

Soil Texture

The results (Table 3) indicate that most of ndiva (80%), bench terraces (82%) and boda (85%) were located on clay, clay loam and sand clay soils, whereas most of stone terraces (86%) were located on sand loam, sand clay loam and clay loam soils. Clay soils are good for ndiva because of high water retention capacity and low seepage and percolation rates. Clay soils are also suitable for boda because of high water holding capacity.

Land Cover

As depicted in Table 4, 60%, 86%, 86% and 56% of Ndiva, stone terraces, bench terraces and boda, respectively, were located on cultivated areas.

Rivers

As shown in Table 5, most of the technologies were

Table 6: Parameters for identifying potential sites for ndiva and their specific suitability levels per parameter

Factor	Level of suitability				
	Highly suitable	Suitable	Moderately suitable	Marginally suitable	Not suitable
Soil texture	Clay	Silty clay	Clay Loam Sandy Clay	Sandy Clay Loam Silty Clay Loam	Other textural classes
Slope (o)	18-30	10-18	5-10	2-5	< 2
Drainage (m)	0 - 125	125 – 250	250 - 350	350 - 500	> 500
Land use/	C	OB	OBS	OWB	RV

Key: C = Croplands/cultivated, OB = Open Bushlands, OBS = Open Bushlands with scattered trees, OWB = Open woodlands with bushlands, RV = Riverine Vegetation

Table 7: Parameters for identifying potential sites for stone terrace technology and their specific suitability levels per parameter

Factor	Level of suitability				
	Highly suitable	Suitable	Moderately suitable	Marginally suitable	Not suitable
Soil Texture	Sandy Loam	Sandy Clay Loam	Clay Loam	Loamy Sand & Sandy Clay	Other textural classes
Soil Depth (cm)	> 100	50 – 100	30 –50	10 - 30	< 10
Slope (°)	18 - 30	10 - 18	5 – 10	2 - 5	0 – 2
Drainage (m)	0 – 125	125 – 250	250 – 350	350 - 500	> 500
Land use	C	OB	OBS	OWB	RV

Key: C = Croplands/cultivated, OB = Open Bushlands, OBS = Open Bushlands with scattered trees, OWB = Open woodlands with bushlands, RV = Riverine Vegetation

located at a distance within 250 m from rivers. With the exception of boda, no technologies were located at distances beyond 350m. Farmers locate technologies close to water sources to easily divert it to the area of use or storage.

Suitability Levels of Determinant Factors and RWH Technologies

Ndiva

Several parameters were found to be associated with Ndiva. Five levels of suitability namely highly suitable, suitable, moderately suitable, marginally suitable and not suitable, were established based on literature and results of the survey. Table 6 gives a summary of parameters and their suitability levels.

Soils with high clay content ranked higher for location of Ndiva than those with lower clay content. This is due to poor internal drainage and high water holding capacity of soils with high clay content. Areas with steep terrain (10°-30°) are more preferred for location of ndiva as water can easily enter and exit by gravity. However, Ndiva are not found on every steep slope since, as a condition, they should be close to water sources with canals supplying water to and out of them (Mbilinyi *at el.*, 2005). With regard to rivers, ndiva were located between 0 and 350m from a stream, with 0 to 125m range being highly suitable (Table 6). River that is more than 500m from ndiva is not suitable as the drains will not be able to supply the required volume of water. Locations of ndiva tend to be more in the low vegetation density cover. These results agree with studies done by Tauer and Humborg (1992) in West Africa, where it was found most of the rainwater storage systems were found in areas with low vegetation.

Stone Terraces

A number of parameters were found to be associated with stone terrace technology. Suitability levels were established based on literature and results of the field survey. Table 7 give the summary of parameters and their suitability levels.

Field studies showed that most stone terraces were in sandy loam soils (Table 7), which are unstable and this agrees with findings of other workers (Hudson, 1981). Therefore, sandy loam was categorized as the optimal soil type for stone terraces. As very few stone terraces were found in loamy sand and sandy clay soils, these were categorized as marginally suitable. Loamy sand has relatively very low available water storage capacity compared to other soils. This property does not favour the location of stone terraces. For example the available water storage capacity for loamy sand is 100mm water/m soil depth, whereas clay loam is 200mm water/m soil depth (Nyvall, 2002). Water retention capacity of a soil is a very important property in RWH systems (Ludovic, 2004). Due to low and unreliable rainfall in the study area, the soils need to store enough water in order to overcome the dry spell during the active growing stages of plants. Another factor could be associated with availability of stones in the area. Stone terraces are adopted where stones are readily available. In unstable soils, the wall of the terrace needs to be held by stones because vegetation alone cannot work (Hudson, 1981). Results of the field survey indicated that most of the stone terraces were located on slopes ranging from 10o – 18o and stone terraces not located on slopes greater than 30o (very steep).

Bench Terraces

A number of parameters were found to be associated with bench terrace technology. Suitability levels were established based on literature (SWMRG, 2004; Ball, 2001; Hudson, 1981; Dent and Young, 1981; Bothale *et al.*, 2002; Foumelis *et al.*, 2004; Moges, 2004) and results of the field survey. Table 8 gives a summary of parameters and their suitability levels.

It has been shown from the results of the field survey that the higher the clay content of the soils, the better are the chances of locating bench terraces. These results agree with findings by SWMRG (2004), which indicated that, sites with clay soils are the most suitable for location of terraces. This could be attributed to the high water storage capacity of clay soils. Another reason that explains why clay content favours location of bench terraces is that, clay soil decreases soil erosion (Hudson, 1981). Soils with high degree of aggregation resist soil erosion than those with low degree of aggregation and stability.

There were no bench terraces located on slopes less than 2°. The results also support earlier findings that steepness of the land is the most important factor in the location of bench terraces (Hudson, 1981). Further, there were no bench terraces located on slopes >30°. Hudson (1981) pointed out that on areas with very steep slopes, bench terraces might not be practical since the riser becomes too high and consequently difficult to maintain and the terraces become too narrow. Bench terraces were located along streams at distances ranging from 0 – 350m, but there were no bench terraces located at distances beyond 350m. These results agree with the findings by Bothale *at el.* (2002). On the other hand, most of bench terraces (76%) were located on areas with low vegetation density.

Boda

Several parameters were found to be associated with

Table 8: Parameters for identifying potential sites for bench terraces and their specific suitability levels per parameter

Factor	Level of suitability				
	Highly suitable	Suitable	Moderately suitable	Marginally suitable	Not suitable
Soil Texture	Clay	Silty clay	Sandy Clay	Sandy Clay Loam & Sandy Loam	Other class
Soil Depth (cm)	> 100	50 – 100	30 -50	10 - 30	< 10
Slope (°)	18 - 30	10 – 18	5 - 10	2 - 5	0 – 2
Drainage (m)	0 - 125	125 – 250	250 - 350	350 - 500	> 500
Land use/cover	C	OB	OBS	OWB	RV

Key: C = Croplands/cultivated, OB = Open Bushlands, OBS = Open Bushlands with scattered trees, OWB = Open woodlands with bushlands, RV = Riverine Vegetation

Table 9: Parameters for identifying potential sites for boda and their specific suitability levels per parameter

Factor	Level of suitability				
	Highly suitable	Suitable	Moderately suitable	Marginally suitable	Not suitable
Soil Texture	Clay	Silty clay	Sandy Clay	Sandy Clay Loam & Sandy Loam	Other class
Soil Depth (cm)	> 100	50 – 100	30 -50	10 – 30	< 10
Slope (°)	< 2 - 5	5 - 10	10 - 18	18 - 30	>30
Drainage (m)	0 - 125	125 – 250	250 - 350	350 – 500	> 500
Land use/cover	C	OB	OBS	OWB	RV

Key: C = Croplands/cultivated, OB = Open Bushlands, OBS = Open Bushlands with scattered trees, OWB = Open woodlands with bushlands, RV = Riverine Vegetation

boda technology. As was the case with the other technologies, suitability levels were established based on the results of the field survey. Table 9 gives a summary of parameters and their suitability levels. Field survey results have indicated that most of the boda were located on areas with soils having relatively high clay content and hence higher water holding capacity. These results agree with the findings by Mbilinyi *at el.* (2005). According to Ball (2001) soils with high percentage of clay and silt particles have higher water-holding capacity than coarse textured soils. Results also seem to indicate that prevalence of boda tends to be negatively related to slope steepness. This also agrees with findings obtained by Mbilinyi *et al.* (2005) in the same area. Areas with steep slopes are not suitable for boda since they require more labour for boda construction. Unlike other technologies, the location of boda along streams appears not to be selective in terms of distance up to 500m, although the most common range was 125-250m. Boda were not located at distances beyond 500m. These results agree with the findings by Bothale *at el.* (2002).

Testing of the suitability levels

In testing the applicability of the suitability levels developed, the locations with existing RWH technologies were compared with locations obtained after running the ADSS tool. Table 10 shows the results of the comparison, which indicate that 81.4% RWH technologies were located in the very high and high suitability levels. In other words, the established suitability levels strongly agreed with

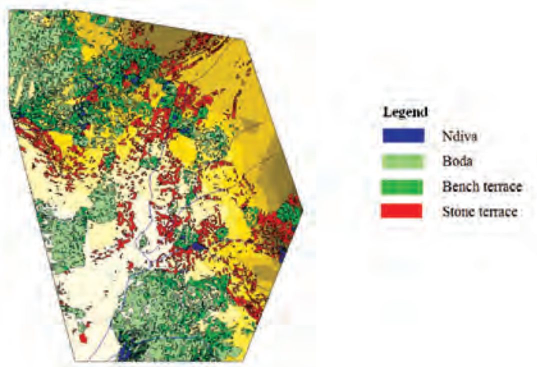

Figure 2: Map of potential sites for different RWH technologies based on the developed suitability criteria.

Table 10: Comparison of RWH technologies actual locations and suitability levels obtained using the DSS framework.

RWH technologies	Level of Suitability				
	Very high	High	Moderate	Low	Very low
Ndiva	2	2	1	0	0
Stone terrace	4	2	7	1	0
Bench terrace	23	15	8	0	0
Bodas	27	39	8	1	0
Total	56	58	24	2	0
Percentage	40.0	41.4	17.2	1.4	0

indigenous knowledge by farmers. Figure 2 shows the resulting classification of the area. Area suitable for ndiva was 0.8%, stone terrace (8.9%), bench terrace (11.0%) and bodas (15.9%) and 63.4% was not classified because of not meeting the set criteria for the investigated technologies. The total area used in the analysis was 805.5 ha.

Summary and Conclusion

Rainfall, slope, soil texture, soil depth, drainage and land use/cover parameters through this study were found to be associated ndiva, boda, and stone and bench terrace technologies. The factors and suitability levels developed in this study can be used together with the DSS framework (Mkiramwinyi, 2006 and Mbilinyi *et al.*, 2007) to determine potential locations for ndiva, stone terraces, bench terraces and bodas.

The information provided can be used without a GIS-based DSS, in which farmer support agents might use the developed tables to guide the locations of ndiva, boda, and stone and bench terrace technologies. However, the use of GIS will assist in prioritizing technologies in area where two or more technologies fall under the same location. For example, an area which is highly suitable for boda but is also highly suitable or just suitable for ndiva, then ndiva will be given priority over boda.

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