# Determination of Suitability Levels for Important Factors for Identification of Potential Sites for Rainwater Harvesting

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## Abstract

*Indigenous and scientific knowledge for locating potential sites for water harvesting technologies do exists, however, 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, pre-requisite for such DSS are the factors and their suitability levels, which are not well developed. This paper focused on development of suitability levels for most important factors/parameters for identification of such sites, which are soil texture, soil depth, drainage, topography and land use or cover. Specific suitability levels were obtained using both the analysis of existing RWH technology at Makanya river catchment and through literature review. Results of field survey together with literature review showed that suitability levels of factors differ with different RWH technologies. For example, suitable levels/areas for water reservoirs (ndiva) are steep slopes (>30*$^o$*) with clay soils whereas suitable sites for stone terraces are moderately steep slopes (18*$^o$ – 30$^o$*) with sandy loam soils. It was also found that most RWH technologies are located at a distance between 0 and 125m from cropland.*

**Keywords:** *Rainwater harvesting technologies, Decision Support System, Factors, Suitability levels.*

## 1. Introduction

Rainwater harvesting (RWH) is the process of collecting runoff from one area (normally uncropped) for various uses such as provision of domestic and livestock water, production of crops, 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 classified 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 includes terraces (stone and bench), borders and overnight storage reservoirs locally known as *ndiva*. Terraces and borders are basically in-situ RWH technologies.

Indigenous knowledge (IK) for decades has been used for positioning RWH technologies and the technologies have been perfectly sustainable. The reason for this is that they are compatible with local lifestyles, local institutional patterns and local social systems (Mbilinyi *et al*., 2005). 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 build on it. More researchers, planners, agricultural extension workers and development practitioners have come to realize the potential of IK.

Georgakakos *et al*., (2002) defined a DSS as an interactive, computer graphics-based programs incorporating appropriate mathematical optimisation and/or simulation models, sometimes together with more qualitative-based rule or linguistic algorithms, and designed to address the questions or issues pertaining to specific problems at specific sites. Therefore, in any DSS, the key are the mathematical or rule-based or linguistic relationships required to address the questions or problems. 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 the influence of important factors in locating different types of RWH technologies is essential, because this will help in developing mathematical and rule-based algorithms for identifying suitable sites for those technologies.

Since most of the decisions to be made are spatial, different layers of the important factors will need to be combined to determine suitability. Normally, multi-criteria evaluation techniques are used in combining the different factors. In multi-criteria evaluation, suitability levels 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 mild slopes. Therefore, the suitability values for the steep slope will be very small whereas for mild slope will be relatively high.

There is a significant literature on suitability of the various factors mentioned in relation to general RWH techniques. Since, some RWH techniques are site-specific and indigenous knowledge exists in those sites, there is a need for studying those locations and the existing knowledge of those techniques and establish a clear relationship between those factors and the existing techniques. The Makanya watershed has relatively high adoption of various types of RWH technologies (SWMRP, 2001). Therefore, the watershed is one of ideal sites for studying the relationship between the various factors and the existing technologies.

Therefore, the main objective of the study was to determine and characterize the determining factors for identifying potential sites for RWH technologies. The specific objectives of the study were to determine:

- the relationships between RWH technologies and determining factors.
- the suitability levels of the determining factors in locating the positions of RWH technologies.

## 2. Factors for identification of potential sites for RWH

In identifying potential sites for water harvesting, the most important parameters include rainfall, soil texture and depth, topography, drainage conditions, and land use or vegetation cover (Prinz *et al*., 1998).

### Rainfall

The knowledge of rainfall characteristics (intensity and distribution) for a given area is one of the pre-requisites for designing a water harvesting system. The availability of rainfall data series in space and time and rainfall distributions is important for rainfall-runoff process 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 ranges from 100 – 700 mm/year and the minimum precipitation for practicing rainwater harvesting is around 200 mm/year. Thus 100 – 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 highly suitable and greater than 600 mm/year is optimally suitable.

Areas with high annual rainfall are relatively more suitable locations for RWH technologies since it is commonly assumed that the quantity (volume) of runoff is a proportional (percentage) of the rainfall depth. Thus, Runoff [mm] = K x Rainfall depth [mm], where K is the percentage of runoff resulting from a rainstorm (Moges, 2004).

### Soil texture

Texture is an important soil characteristic because it will, to some extent, determine water intake rates (absorption) 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). Moreover, the size and spacing of soil particles determine how much water can flow in. Wide pore spacing at the soil surface increases the rate of water infiltration, thus coarse soils have a higher infiltration rate than fine soils (Ball, 2001).

### Soil depth

Generally, the deeper the soil depth the higher the water storage capacity and vice versa also providing a greater amount of total nutrients for plant growth than the shallow one (Moges, 2004). According to FAO (1990) soil depth can be categorized as very shallow (< 30 cm), shallow (30-50 cm), moderately deep (50-100 cm), and deep (100-150 cm). Sites with deep soils are relatively suitable for location of RWH technologies than shallow one as deep soils have higher capacity of storing the harvested runoff as well as providing a greater amount of total nutrients for plant growth than the shallow one (Moges, 2004).

### Topography

The landforms along with slope gradient and relief intensity are other parameters to determine the type of water harvesting (Prinz *et al*, 1998). To ensure high runoff efficiency, the slope of a catchment should be as steep as possible. However, slope of more than 5% are susceptible to high erosion rates. Where the catchment has slopes steeper than this, erosion control measures are therefore necessary (Hatibu and Mahoo, 2000). With a given inclination, the runoff volume increases with the slope. The slope can be used to determine the suitability for macro-or micro- or mixed water harvesting systems decision making (Prinz *et al*, 1998). According to Dent and Young (1981), slope can be categorized as follows: level to gentle ($0^0 – 2^0$), gentle ($2^0 – 5^0$), moderately undulating ($5^0$ - $10^0$), moderately steep ($10^0$ - $18^0$), steep ($18^0$ - $30^0$), very steep ($30^0$ - $45^0$), and precipitous vertical (> $45^0$).

### Land use or vegetation cover

Vegetation is another important parameter that affects the surface runoff. Studies in West Africa (Tauer and Humborg, 1992) proved 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. Vegetation density can be characterised by the size of the area under vegetation. There is a high degree of congruence between density of vegetation and suitability of the soil to be used for cropping (Tauer and Humborg, 1992). A decrease in the vegetation density results in increase volume of runoff thus, densely covered with vegetation, yields less runoff than bare ground (Moges, 2004). Moreover, Hatibu and Mahoo (2000) depicted that vegetation cover has several effects on the effective rainfall and runoff. These include: interception and thus evaporation from canopy, increased surface ponding and slowing down of water which assist infiltration and thus reduce runoff yield and increase hydraulic conductivity due to root channel which also leads to increased infiltration. Vegetation also consumes a lot of water through evapotranspiration and thus reduces the total amount of runoff yield by a catchment. Similarly, Foumelis *at el*., (2004) pointed out the related conclusion that dense vegetation cover reduces the availability of water by intercepting the rainfall through absorption and evapotranspiration.

### Drainage patterns

The suitability for cropping area of a water harvesting system depends on the drainage density. The drainage density is a good indicator of the suitability of the area for water harvesting, areas with high drainage density will rank higher in suitability for cropping area of a water harvesting system than area with low drainage density (Prinz *et al*., 1998). Water harvesting structures located at a great distance from the river(s) has a much greater potential for water loss due to evaporation and seepage (Risinger and Turner, 2004). It is, therefore, suggested that distances closer to the river are more desirable for locating water harvesting structures. Bothale *at e*l., (2002) described that water harvesting structures are preferred along streams at distances of about 500 m distance on either side of the river (a buffer of 1 km) is sufficient.

It is important to note 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.

## 3. Methodology

### Study Area

Bangalala village in the Makanya watershed (Figure 1) was selected as a site for development of the DSS. The site was selected based on the intensiveness of RWH practices, which could assist in the assessment and identification of potential sites for RWH technologies.

The rainfall pattern in the study area is bimodal, with mean annual rainfall of approximately 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 composed of steep rocky hills with slopes ranging from $18^0 – 52^0$ and the altitude ranges between 830 m and 1042 m above mean sea level (amsl).

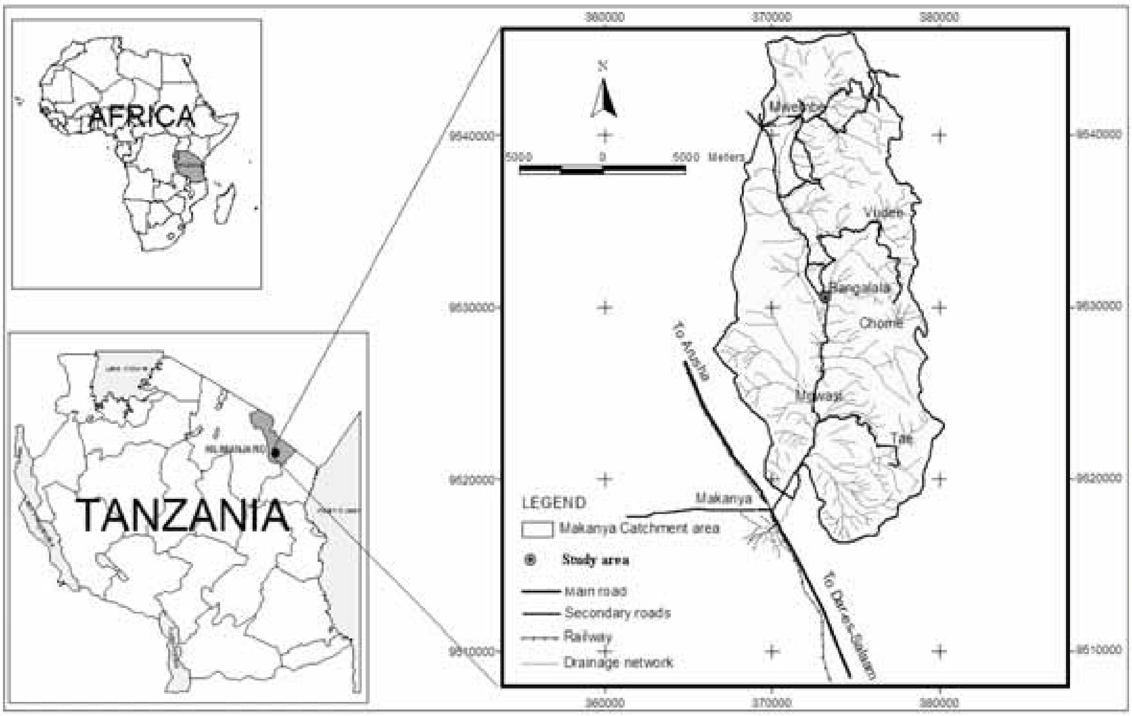

**Figure 1: Map showing Makanya watershed in Same District, Northern Tanzania**

The whole Western part of the catchment drains to Makanya village (Figure 1). Two drainage systems, one originating from Tae area (Mangoloma River) and another one from Mwembe, Chome and Vudee (Vudee River), join together at Kimunyu in Mgwasi village.

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.

The most dominant farming system is agro-pastoralism. Agriculture is practised in the form of mixed farming, whereas maize is intercropped with legume crops (beans, green grams, lablab bean,). Apart from maize and legumes, other crops include bananas, sugarcane and vegetables.

## 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 or vegetation cover, drainage pattern and rainfall.

### *Soil texture and soil depth*

At the beginning of the field survey, interpretation of aerial photographs of 1983 was carried out visually and stereoscopically. Landform, vegetation cover and drainage patterns were extracted 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 also used to describe the soil. Soil colours were described using Munsell Soil Colour charts (Munsell Soil Colour Company, 1954). Surface stoniness, rock outcrops, topography, elevation and GPS readings were also observed and recorded.

Soil textural names were given to the soil based upon the relative proportions of each of three soil separates – sand, silt and clay and soil depth 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 Arc View GIS software.

### *Topography*

Differential GPS was used to record coordinates and elevations, at every 100 meters or less, along transect lines. The data was processed in a GIS environment to produce contour map that was used to construct a Digital Elevation Model (DEM). Using the Surface Analysis menu in Arc View software, 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 technologies: (1) optimally suitable (2) highly suitable (3) moderately suitable (4) marginally suitable (5) not suitable.

### *Land use/cover*

Visual and stereoscopic interpretation of aerial photographs (at scale of 1: 65,000) was 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 attributes for identifying the land use/cover types namely open woodland, open bushland, open bushland with scattered trees, and cropland. Land use/cover types were then categorized into five (5) suitability classes: (1) optimal Suitable (2) highly suitable (3) moderately suitable (4) marginally suitable (5) not suitable.

### *Drainage patterns*

Drainage patterns were digitised directly from the topographic sheet of 1988 at scale of 1: 50,000. Buffer map, showing different suitability area in term of distance from drainage patterns/streams, was then extracted from the drainage pattern using Arc View GIS software. Based on Bothale *at el.*, (2002), the distances from the drainage pattern were categorized into the following suitability classes: 0 – 125 m (optimally suitable), 125 – 250 m (highly suitable), 250 – 350 m (moderately suitable), 325 – 500 m (Marginally suitable) and more than 500 m (not suitable).

### *Rainfall*

The rainfall level of suitability for RWH technologies was determined based on data observed at Hassan Sisal Estate and Suji mission from year 1991 to 2002 seasons. These rainfall meteorological stations are nearby the study area. based on mean annual rainfall data obtained from these stations and information described by Prinz, (1996), rainfall map of suitability level ranging from moderately suitable to highly suitable 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 intensive literature review. The suitability levels were assigned a value on a scale of 1 to 9 (Table 1). This ranking system was selected for the factors variables 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).

**Table 1: Numerical expression of suitability levels**

| Suitability Level | Numerical expression |
|---|---|
| Optimally suitable | 9 |
| Highly suitable | 7 – 8 |
| Moderately suitable | 6 –5 |
| Marginally suitable | 4 – 3 |
| Not suitable | 2 –1 |
| Restricted | 0 |

Source: (Burnside *et al.,* 2002), cited in Diamond and Parteno (2004).

## 4. Results and Discussions

### Determinant Factors and RWH Technologies

### *Slope*

The results showed that the highest percentage of *ndiva* (80%) were located on slope ranging from 18° – 30° and 10° - 18°, while 53.7% of stone terraces were located on moderately steep slopes (10° - 18°). The highest percentage (41.3%) of bench terraces were located on slopes ranging from 5° - 18° and very few were located on slopes between 2° - 5°. Most of borders were located on slope ranging from 2° - 5° and very few on slopes between 18° - 30° (Table 2). In addition, the results depicted a general trend of location of the technologies on slope classes in the area. *Ndiva* are located on steep slopes followed by stone terraces, then bench and lastly boarders.

**Table 2: Occurrence of RWH technologies on different slope ranges**

| Slope( °) | Ndiva | | Stone terrace | | Bench terrace | | Border | |
|---|---|---|---|---|---|---|---|---|
| | 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 |

### *Soil Depth*

The results (Table 3) showed 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 located in moderately deep soils, whereas most of the borders (59%) were located on deep soil (100 – 150 cm).

**Table 3: Occurrence of RWH technologies on different soil depth.**

| Soil depth(cm) | Stone terrace | | Bench terrace | | Border | |
|---|---|---|---|---|---|---|
| | Frequency | % | Frequency | % | Frequency | % |
| 10 – 30 | 2 | 14.3 | 3 | 6.3 | 1 | 1.3 |
| 30 – 50 | 8 | 57.1 | 11 | 22.9 | 11 | 14.1 |
| 50 – 100 | 4 | 28.6 | 30 | 62.5 | 20 | 25.6 |
| 100 – 150 | - | - | 4 | 8.3 | 46 | 59.0 |
| Total | 14 | 100.0 | 48 | 100.0 | 78 | 100.0 |

### *Soil Texture*

The results from Table 4 indicated that most of *ndiva* (80%), bench terraces (82%) and borders (85%) to be located on clay soils, whereas most of stone terraces (86%) were located on loam soils. According to farmers, clay soils are good for *ndiva* because of high water retention capacity and low seepage and percolation rates. Clay soils are also suitable for Ridges and borders because of high water holding capacity.

**Table 4: Occurrence of RWH technologies on different soil texture.**

| | Ndiva | | Stone terrace | | Bench terrace | | Border | |
|---|---|---|---|---|---|---|---|---|
| Soil texture | 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 | - | - | 14 | 29 | 31 | 40 |
| Clay | 3 | 60 | - | - | 18 | 38 | 35 | 45 |
| Total | 5 | 100 | 14 | 100 | 48 | 100 | 78 | 100 |

### *Land Cover*

As expected, the results showed that most of the technologies are located in cropland. As depicted in Table 5, 60%, 86%, 86% and 56% of *ndiva*, stone terraces, bench terraces and borders, respectively, were located on cultivated areas.

**Table 5: Occurrence of RWH technologies on different land cover/use.**

| Land cover/use | Ndiva | | Stone terrace | | Bench terrace | | Border | |
|---|---|---|---|---|---|---|---|---|
| | 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 |

### *Drainage*

As depicted in Table 6, most of the technologies were located on distance between 0 and 250 m from water sources. With an exception of borders (2.7%), no technologies were located on distances beyond 350 m. *Ndiva* needed to be close to the source of water recharge, particularly streams or ephemeral flows, since it is water storage structure. Similarly, farmers located other technologies close to water sources to increase the probability of getting water and hence land productivity.

**Table 6: Relationship between RWH technologies and distance from drainage channels.**

| Drainage (m) | Ndiva | | Stone terrace | | Bench terrace | | Border | |
|---|---|---|---|---|---|---|---|---|
| | 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 |

## Suitability Levels of Determinant Factors and RWH Technologies

### *Ndiva*

Several parameters were found to be associated with *ndiva*. Five (5) suitability levels, namely optimally suitable, highly suitable, moderately suitable, marginally suitable and not suitable, were established based on literature review and results of the field survey. Table 7 gives the summary of parameters and their suitability levels.

**Table 7: Parameters for identifying potential sites for ndiva and their specific suitability levels.**

| Factor | Level of suitability | | | | |
|---|---|---|---|---|---|
| | Optimally suitable | Highly suitable | Moderately Suitable | Marginally suitable | Not suitable |
| Scale | 9 | 8-7 | 6-5 | 4-3 | 2-1 |
| Soil texture | Clay | Silty clay | Clay Loam<br>Sandy Clay | Sandy Clay Loam<br>Silty Clay Loam | Other class |
| Slope (%) | > 300 | 180 - 300 | 100 – 180 | 50 - 100 | < 50 |
| Drainage (m) | 0 - 125 | 125 – 250 | 250 – 350 | 350 - 500 | > 500 |
| Land use/ | C | OB | OBS | OWB | R |

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

Soil with high percentages of clay content was ranked higher for location of *ndiva* than the one with lower percentages. Sloppy terrain areas 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 they should be close to water sources with canals supplying water to and out of them (Mbilinyi *at el.*, 2005). With regard to drainage, *ndiva* were located between 0 and 350 m from a stream, with 0 to 125 m ranges being optimally suitable (Table 6). These results agree with studies done by Bothale *at el.* (2002), which described that, water harvesting structures are preferred along streams, and 500 m distances on either side of the river (buffer of 1 km) is sufficient. Drainage that is more than 500 m from *ndiva* is not suitable as the drains will not be able to give required volume of water. Locations of *ndiva* tend to be more in the low vegetation density cover and relatively less in high vegetation density cover. These results agrees with studies done by Tauer and Humborg (1992) in West Africa. Therefore, based on vegetation density (Tauer and Humborg, 1992) and the results of the field survey, five (5) suitability levels were established as shown in Table 6.

### *Stone Terraces*

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

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

| **Factor** | **Level of suitability** | | | | |
|---|---|---|---|---|---|
| | Optimally Suitable | Highly suitable | Moderately suitable | Marginally suitable | Not suitable |
| | 9 | 8-7 | 6-5 | 4-3 | 2-1 |
| Soil Texture | Sandy Loam | Sandy Clay Loam | Clay Loam | Loamy Sand & Sandy Clay | Other class |
| Soil Depth (cm) | > 100 | 50 – 100 | 30 –50 | 10 - 30 | < 10 |
| Slope (%) | $18^{o}$ - $30^{o}$ | $10^{o}$ - $18^{o}$ | $5^{o}$ – $10^{o}$ | $2^{o}$ - $5^{o}$ | $0^{o}$ - $2^{o}$ |
| 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

Based on information given by Hudson (1981) and results of the field survey, five (5) suitability levels for soil texture, soil depth, slope, drainage and land use/cover were established as indicated in Table 7. Field studies found that most stone terraces were located in sandy loam soils, which is unstable soil and this agrees with Hudson findings. Therefore, sandy loam was categorized as the optimal soil for stone terraces. Very few stone terraces were found in loamy sand and sandy clay and therefore categorized as marginal suitable. Loamy sand has the 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 whereas clay loam is 200mm water/m soil (Nyvall (2002). Water retention capacity of a soil is 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 available, since in unstable soils the wall of terrace needs to be held by stones because vegetation alone cannot work (Hudson, 1981). Results indicated that most of stone terraces were located on slope ranges from $10^o$ – $18^o$ and no stone terraces were located on slopes greater than $30^o$ (very steep). The results support previous findings by Hudson (1981), which explained that in areas with very steep slopes, terraces might not be practical since the riser becomes too high and consequently difficult to maintain and the terraces become too narrow.

### *Bench Terraces*

A number of parameters were found to be associated with bench terrace technology. Suitability levels were established based on literature reviews and results of the field survey. Table 8 give the summary of parameters and their suitability levels.

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

| Factor | Level of suitability | | | | |
|---|---|---|---|---|---|
| | Optimally suitable | Highly suitable | Moderately suitable | Marginally suitable | Not suitable |
| | 9 | 8-7 | 6-5 | 4-3 | 2-1 |
| 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 (%) | $18^0 - 30^0$ | $10^0 - 18^0$ | $5^0 - 10^0$ | $2^0 - 5^0$ | $0^0 - 2^0$ |
| 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

Results showed that location of bench terraces increased as clay content percentage increased. These results agree with studies done by SWMRG (2004), which indicated that, sites with clay soils are the most excellent for terraces location. This could be explained by high water storage capacity of clay soils. Soils with smaller particles like clay and silty have a larger surface area than those with larger particles, and a large surface area allows a soil to hold more water. In other words, a soil with a high percentage of silt and clay particles, which describes fine soil, has a higher water-holding capacity (Ball, 2001). Another reason that explains why clay content favours location of bench terraces is that, a clay soil decreases soil erosion (Hudson, 1981). Soils with high degree of aggregation into soil particles, and the stability of the particles like clay resist soil erosion than those with low degrees of aggregation and stability. Based on the above results of the field survey, information given by SWMRG (2004), Ball (2001) and Hudson (1981) suitability levels were established as shown in Table 8. There were no bench terraces located on the slopes less than $2^0$ - $5^0$. The results also support earlier findings that explained that steepness of the land is the most important factor in the location of bench terraces (Hudson, 1981), also there were no bench terrace located on slopes >$30^0$. Hudson (1981) explained 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 became too narrow (Hudson, 1981). Based on information given by Dent and Young (1981) and Hudson (1981), and the results of the field survey, five suitability levels were established as shown in Table (Table 8). Bench terraces were located along streams with distance ranging from 0 – 350 m, and there were no bench terraces located on distance beyond 350m. These results agree with studies done by Bothale *at el*. (2002). Most of bench terraces (76%) were located on low vegetation density. Based on vegetation density (Tauer and Humborg, 1992; Foumelis *at el*., 2004; Moges, 2004) and the above results, five (5) suitability levels were established as shown in Table 8.

### *Borders*

Several parameters were found to be associated with border technology. Suitability levels were established based on literature reviews and results of the field survey. Table 9 give the summary of parameters and their suitability levels.

**Table 9: Parameters for identifying potential sites for borders and their specific suitability levels per Parameter**

| Factor | Level of suitability | | | | |
|---|---|---|---|---|---|
| | Optimally suitable 9 | Highly suitable 8-7 | Moderately suitable 6-5 | Marginally Suitable 4-3 | Not suitable 2-1 |
| 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 (%) | < $2^0$ - $5^0$ | $5^0$ - $10^0$ | $10^0$ - $18^0$ | $18^0$ - $30^0$ | >$30^0$ |
| 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

Results showed that most of borders were located on the soil textural classes with higher clay. This result agrees with studies done by Mbilinyi *at el*. (2005), which have reported that, soils with high water holding capacity are the most excellent for borders location. According to Ball, (2001) soil with high percentage of clay and silt particles have higher water-holding capacity than coarse soils. Smaller particles (silt and clay) have larger surface area than those with larger particles, and large surface area allows soils to hold more water. In addition, the results showed that locations of borders tend to increase as slope decreases. The result agreed with findings obtained by Mbilinyi *at el.* (2005) in the same area, which showed that, area suitable for construction of borders are areas with medium to low slopes. Areas with steep slopes are not suitable for border since they require more labour for border construction. Regarding to drainage, results showed that borders were located along streams with distance ranging from 0 – 500 m, and there were no border located on distances beyond 500 m. These results agree with studies done by Bothale, *at el.* (2002). As in Tauer and Humborg (1992), the results showed that locations of borders tend to increase with decrease of vegetation density.

## 5. Summary and Conclusions

Several parameters (rainfall, slope, soil texture, soil depth, drainage and land use/cover) were found to be associated with various RWH technologies. RWH technologies were located differently on deferent suitability levels of a factor. Therefore there is a relationship between location of RWH technologies and suitability levels of factors.

DSS is merely a tool, which provide means and facilitate the identification of potential sites for RWH technologies without the knowledge about appropriate suitability levels such tools would be useless.

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