GIS-BASED ASSESSMENT OF RAINWATER HARVESTING POTENTIAL AREAS OF HARSHIN DISTRICT, SOMALI REGION, ETHIOPIA

M.SC. THESIS

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JANUARY 2019

HARAMAYA UNIVERSITY, HARAMAYA

GIS-Based Assessment of Rainwater Harvesting Potential Areas of Harshin District, Somali Region, Ethiopia

A Thesis Submitted to the School of Graduate Studies
HARAMAYA UNIVERSITY

In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN IRRIGATION ENGINEERING

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January 2019
Haramaya University, Haramaya

HARAMAYA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

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BIOGRAPHICAL SKETCH

The author was born in October 22, 1977 at Dire Dawa, Ethiopia. He pursued his elementary education at Alliance France Elementary School and his junior and secondary educations at Abuna Endrias. After completing his high school education at Notre Dame School, Dire Dawa in June 1995, he joined Awassa College of Agriculture and graduated with Diploma in Agricultural Engineering and Mechanization in June 1997. After graduation, the author was employed at Jimma Zone Agricultural Office as soil and water conservation & irrigation expert for three and half years.

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ACKNOWLEDGEMENTS

I would like to thank Allah for He has provided me all the time I needed most and all the good people to help me.

I feel deeply indebted and express my sincere gratitude to my advisor Dr. Tena Alamirew for all the wealth of knowledge passed on to me during my studies, and for his critical review of the thesis manuscript that eased the compilation of my thesis work.

My appreciation and sincere heartfelt gratitude is due to Dr. Sultan Wali for his guidance and constructive comments, moral and transport service he provided me during my research work.

My gratefulness and thanks is to federal Ministry of Agriculture for granting me the research fund and Gode ATVET College for logistic support, encouragement and contributions in facilitating the conditions at the time of joining the University for this Study. Special appreciation to Ato Daniel Siyoum for he was with me in the field in the whole dusty areas while soil sampling and field surveying.

I would like also to extend my appreciation and thanks to Ato Girma Moges, for his kind collaboration, encouragement and sharing of knowledge and helping me out from all the tiresome software utilization.

Great appreciations to my special friend Ato Mebratu Tesfa for hosting me in all the times of hardship, lovely friendship, support, encouragement and being constant sources of my strength and hope in every aspect of my life.

Last but not least, I would like to forward special thank and deep appreciation to my wife S/r Kemeria Awel for her confidence and never ending concern, support and encouragement. I have no words to appreciate her commitment, strength and patience paying for our love and relationship.

One thing I learned from all of you is after all these years; you tracked me back where I should have been long ago, thank you.

ACRONYMS AND ABBREVIATIONS

ADLI	Agricultural Development-Led Industrialization
AHP	Analytical Hierarchy Process
CA	Catchment Area
CBO	Community-Based Organizations
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
GPS	Global Positioning System
GIS	Geographic Information System
IDW	Inverse Distance Weight
MCE	Multi Criteria Evaluation
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis
OIDA	Oromiya Irrigation Development Authority
RS	Remote Sensing
RWH	Rainwater Harvesting
SR	Somali Region
WHT	Water Harvesting Technique
WLC	Weighted Linear Combination
WOP	Weighted Overlay Process

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GIS-BASED ASSESSMENT OF RAINWATER HARVESTING POTENTIAL AREAS OF HARSHIN DISTRICT, ETHIOPIA SOMALI REGION, ETHIOPIA

ABSTRACT

In Somali Region (SR), water has always been a critical resource. It has been in short supply for many years. Since 1996, the Somali Region has been either in a state of drought, recovering from a drought or moving into a new drought. Similarly, 90% of Harshin district communities dwell in the rural area depending mainly on livestock production for their livelihood; where the water supply in Harshin is totally from surface water system through rainwater harvesting (RWH). Thus, a systematic identification of areas suitable for RWH is essential to ensure its effectiveness, mitigate dry spells and better target investments in RWH. Therefore, the objectives of this study were to develop a GIS-based approach for identifying suitable sites for pond rainwater harvesting in Harshin District of Somali Region and to integrate factors for locating and mapping suitable areas for RWH interventions. This study used a GIS-based suitability model to generate suitability map for pond RWH by combining different criteria through Multi Criteria Evaluation (MCE) process. The suitability criteria considered were soil, climate, topography, land cover and rainfall. Maps for each criterion were prepared using ArcGIS and assigned weights according to their relative importance in prioritizing potential areas suitable for pond RWH. Accordingly, the spatial distribution of the suitability map showed that about 45.69% of the Harshin land falls under highly to very highly suitable category which covers around 1,968.90 Km^2 of land, the moderately suitable class is about 54.29% which covers about 2,239.49 Km^2 areas. The less and non-suitable land of this district for pond RWH is 0.01% which accounts for 0.61Km^2 of land. It is concluded that suitability modelling using GIS was a flexible, time efficient and cost effective method for accurate identification of potential areas for RWH that facilitates decision-making in RWH.

1. INTRODUCTION

Water is among the critical factors that pose threat to agricultural productivity and environmental sustainability. Much of the low agricultural productivity is observed in regions where water is an uncertain resource. Water is indeed an uncertain factor, in particular in sub-Saharan Africa because of droughts and dry spells, and global environmental change is to exacerbate this uncertainty (IPCC, 2012). Africa's dependence on rainfed agriculture means that it is susceptible to climatic variability which can severely affect food production and, therefore, human security and export revenues. Based on the assessment of vulnerabilities and risks of climate change in Kenya, Malawi and Ethiopia, climate-change emission scenarios revealed more extreme events in the future that could destabilise development activities (UNDP, 2007).

Irrigation does not currently play a significant role in African agriculture. Despite highly variable, in many cases insufficient rainfall and high incidence of droughts, food production in Africa is almost entirely rainfed. However, agriculture in sub-Saharan Africa is characterized by low input–output features. Research has shown that there are no agro-hydrological limitations to increasing agricultural production. The low agricultural production is rather due to sub-optimal management (Licker *et al.*, 2010).

Despite the availability of a large volume of fresh water including 12 river basins with an annual runoff volume of 122 billion m^3 and an estimated 6.5 billion m^3 of groundwater potential, Ethiopia is prone to recurring droughts and food insecurity (Awlachew and Ayana, 2011). Ethiopia depends on the rainfed agriculture with limited use of irrigation for agricultural production. It is estimated that more than 90% of the food supply in the country comes from low productivity rainfed smallholder agriculture and hence rainfall is the single most important determinant of food supply and the country's economy. The major problem associated with the rainfall-dependent agriculture in the country is the high degree of rainfall variability and unreliability. Due to this variability, crop failures due to dry spells and droughts are frequent. As a consequence, food insecurity often turns into famine with the slightest adverse climatic incident, particularly, affecting the livelihoods of the rural poor (Belete, 2006).

A proper and planned use of the available water and the improvement of water use efficiency in all sectors of water applications are indispensable. Rainwater harvesting can be practiced to provide water for irrigation, domestic water and water for livestock. It can also serve as a way to replenish groundwater. Water harvesting is suggested as a key option for a sustainable water management strategy to increase agricultural production while balancing the effect on the environment (IAASTD, 2009; Liniger *et al.*, 2011). Rockström and Falkenmark (2015) recommended investing in Rainwater Harvesting (RWH) technologies for agricultural production in contrast to the conventional practices of drawing water from rivers and underground. Rainwater harvesting (RWH) is listed as one of the specific adaptation strategies that the water sector needs to undertake to cope with future climate change as it has the potential to enhance ecosystem and livelihood resilience (Rutashobya, 2008; Mukheibir, 2008; Salas *et al.*, 2009).

Although governmental and non-governmental organizations have been advocating the use of RWH to improve the livelihoods of rural people, the implementation has been confined with a range of problems and its adoption is low. Most of the constructed RWH are not performing as anticipated in terms of harvesting and storing adequate amounts of runoff to meet the water demands particularly for crop production due to various reasons (Alamerew, 2006). One of the reasons could be the lack of scientific information to properly allocate and plan RWH interventions. Currently, most RWH interventions are planned on ad-hoc basis without much knowledge about the location-specific conditions. A more systematic approach to the selection of feasible sites for RWH interventions may improve their performance and rate of adoption.

For the pastoralists in the Somali Region (SR), water has always been a critical issue. It has been in short supply for many years, but the situation is alarming now. If this trend continues, as it is now, the future of the pastoralists in Ethiopia as a whole will be at risk, because there will be devastating consequences for the environment, for the livestock, for the pastoralists and their health, for their economy and for the peace and stability of the affected areas. Due to the lack of holistic planning both at the National and the Regional levels, little efforts have been done to rescue the pastoralists and their livelihoods or even to mitigate their sufferings (Mitiku & Sorrsa, 2002).

However, to the best of my knowledge, for Harshin district of SR GIS has not been used in identification of suitable sites for RWH. This study investigated the use of a GIS-based approach for identifying suitable sites for implementation of pond rainwater harvesting technologies in the study area and a combined effort of GIS analysis and field data were used.

General Objective

To develop a GIS-based approach for identifying suitable sites for pond rainwater harvesting in Harshin District of Somali Region.

Specific Objectives

- To establish factors for locating suitable areas for pond RWH intervention in Harshin District.
- To integrate factors for locating and mapping suitable areas for pond RWH intervention in a GIS based platform and apply the developed integrated GIS based platform to locate land suitable for pond RWH in Harshin District.

2. LITERATURE REVIEW

2.1 RWH Definitions

Global Development Research Center (2002) reported that the first use of RWH techniques is believed to have originated in the Neo Babylonian Empire now called Iraq over 5,000 years ago, in the Fertile Crescent, where agriculture once started some 8,000 BC. Many communities in arid and semi-arid regions have been harvesting water for many years. Examples of water harvesting structures built thousands of years ago are known from the Babylonians, Israel, Tunisia, China and the America's. Such structures have received renewed attention with the implementation of policies to increase food production since the droughts and food crises in sub-Saharan Africa in the 1970's and 1980's (Ouessar *et al.*, 2004). Modern water-harvesting research was started in the 1950's by Geddes in Australia. Geddes, as quoted by Myers (1975), gave the first definition of water harvesting: 'The collection and storage of any farm waters, either runoff or creek flow, for irrigation use.'

Differences in the definition of water harvesting across the literature mostly relate to the purpose of water storage, the type of storage, and whether the source of water is *in-situ* or *ex-situ* (Pachpute *et al.*, 2009; Rockstrom *et al.*, 2010). Kahinda *et al.* (2008) defined RWH as the collection, storage and use of rainwater for small-scale productive purposes. According to Mzirai and Tumbo (2010) RWH is the process of intercepting and concentrating rainwater in order to increase water infiltration into the soil for direct use by plants or in reservoirs for later application when needed to mitigate dry spells. Mekdaschi & Liniger (2013) defined it as: "The collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance".

All water-harvesting systems consist of the following components (Oweis *et.al.*, 2012):

- A catchment: the part of an area from which some of the rainfall is harvested. It is also known as a runoff area. This area can be a few square meters to several square kilometers in size and may be agricultural, rocky, a paved road, or a rooftop.
- A storage facility: the area that holds the harvested runoff water until used for crops, animals, or people. Water can be stored above ground (e.g. reservoirs or ponds), in the soil profile, and in underground storage containers (e.g. cisterns).

- A target: the endpoint of a water-harvesting system, where the harvested water is used for crop production or domestic use.

2.2 RWH Classifications

The water harvesting systems are generally classified into *ex-situ* and *in-situ* water harvesting systems (Dile *et al.*, 2013). The collected water can be directly channelled to the field for infiltration into the soil (*in-situ*) or stored in a reservoir or tank (*ex-situ*) to be utilized elsewhere at another time. Generally, stored water could be used for agricultural and domestic purposes (Mzirai and Tumbo, 2010).

RWH technologies and systems can be classified in several ways, mostly based on the runoff generation process, size of the catchment and type of storage. Runoff generation criteria yields two types of systems *i.e.* runoff based systems (runoff concentrated from a catchment) and *in-situ* water conservation (rainfall conserved where it falls). The runoff storage criteria yield two categories, *i.e.*, storage within the soil profile and storage structures. The size of catchment yields two categories, *i.e.*, macro catchments and micro catchments (within field). UNEP (2009) breaks the rainwater harvesting systems down into two main areas of *in-situ* and *ex-situ* technologies, as well as man-made/ impermeable surfaces as shown in Figure 2.

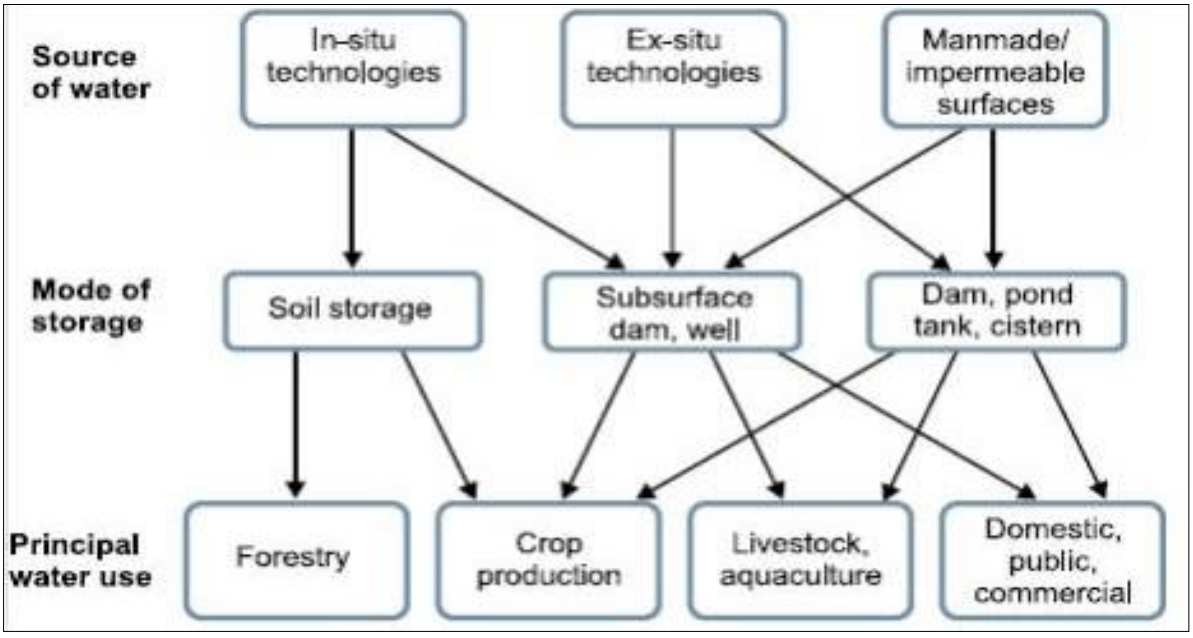

Figure 1: Rainwater harvesting systems, mode of storage and use of water UNEP (2009)

According to UNEP (2014) *in-situ* RWH involves small movements of rainwater as surface runoff. In order to concentrate the water, there is no separation between the collection and the storage area. The water is collected and stored where it is going to be utilized. In-situ water conservation includes small basins, pits and cultural field practices which harvest water within the fields. In this application there is no separation between the collection area and the storage area, water is collected and stored where it is going to be used. In situ water harvesting practices, besides improving soil fertility and preventing soil erosion, can enhance soil moisture (Liniger *et al.,* 2011). Field studies from Northern Ethiopia on in-situ water harvesting systems such as tied-ridging, open ridging and sub-soiling improved soil water content in the root zone during cropping period compared to the traditional tillage by 24%, 15% and 3% respectively (McHugh *et al.*, 2007). Similarly, Araya and Stroosnijder (2010) conducted tied ridging and mulching experiment on barley field in similar region and observed increased soil water in the root zone by more than 13%compared to the control. Consequently, in-situ water harvesting practices contributed to dry spell mitigation and yield improvements.

There are two reasons why we make this distinction; reservoir storage (*ex-situ)* makes it possible to apply supplementary irrigation whereas in soil storage (*in-situ)* does not. Since, systems that allow for supplementary irrigation are better geared towards ameliorating the impacts of intra-seasonal dry spells (Röckstrom *et al.*, 2010; Nyakudya and Stroosnijder, 2011), we expect reservoir storage techniques to have a larger impact on crop yields in low rainfall years. In soil storage and reservoir storage technologies differ in terms of investment and maintenance costs. Most in soil storage structures require limited investments but substantial (labour) costs; heavy rains may damage the structures and investments like planting pits need to be re-done annually. Reservoir storage structures, on the other hand, require substantial initial investments, but once they have been constructed maintenance costs are relatively low (Lasage and Verburg, 2015).

Recently, the Ethiopian government and Non-Governmental Organizations (NGOs) have been promoting *ex-situ* water harvesting systems at household level to enhance water availability for crop production, domestic use and watering of livestock. Most of the RWH systems were developed in food insecure Woredas/ Districts, which are vulnerable to drought and where emergency situations occurred in the past. The four most common types of *ex-situ* household RWH reservoirs in Ethiopia are: unlined excavations, excavations compacted with clay, excavations lined with plastic and excavations lined with cement.

The first three are referred to as ponds while cemented excavations are called tanks (Girma M. *et al.*, 2011).

2.3 History and Status of RWH in Ethiopia

In many parts of Ethiopia, it is often the variability of rainfall, rather than its total seasonal amount, that adversely affects crop production levels. Hence, rainwater harvesting and buffering through times of rainfall scarcity through the application of supplemental or protective irrigation might be a good option to protect loss of crop yields, or even complete crop failure (Belete, 2006).

The history of RWH practices in northern Ethiopia dates back as early as 560 BC, during the Axumite Kingdom. In those days, rainwater was harvested and stored in ponds for agriculture and domestic use (Seyoum, 2003). Other evidences include the remains in one of the oldest castles in Gondar (Fasiludus) from the 17^{th} century which used to have a sophisticated RWH system with a flume used for transporting water to the palace pool used for swimming and religious rituals. In the south of the country, the Konso people have a long and well-established tradition of building terraces to harvest rainwater for producing sorghum under extremely harsh environmental conditions, *i.e.* low, erratic and unreliable rainfall (Alem, 1999).

Despite its long history, only a few decades ago RWH has received renewed attention from policy makers. According to promotion and application of RWH techniques addressing water scarcity began through the government-initiated soil and water conservation programs as response to the 1971-1974 (during Derg regime) drought in Tigray, Wollo and Hararghe (Seyoum, 2003). However, the intervention was limited because of the low level of community participation and declining attention by the government.

After the fall of the military Derg regime, both the Transitional Government of Ethiopia (TGE) established in 1991 and the Federal Democratic Republic of Ethiopia (FDRE) established in 1995, adopted the Agricultural Development-Led Industrialization (ADLI) strategy which emphasizes improvement in agricultural productivity to achieve food security and sustainable development. Besides recognizing the problem of variability in the rainfall distribution across the country, the strategy advocates water-centred sustainable rural development (Desta, 2004). Based on this, many different RWH technologies have

been developed by regional states, NGOs, communities and individual farmers throughout the country.

Water is considered as one of the three pillars (land, labour and water) for the development in the Ethiopia's Agricultural Development Led Industrialization (ADLI) policy and food security programs. The Ethiopian government has committed financial resources to increase the irrigated area (Soriano, 2007). Rainwater harvesting technologies at the village or household level are proposed by the government of Ethiopia as a practical and effective alternative to improve the livelihoods of rural people at little cost and with minimal outside inputs. The Ministry of Agriculture & Rural Development (MoARD) and respective regional bureaus planned and implemented aggressive and ambitious water harvesting programs along the country's food security programs (Desta, 2006).

The Ethiopian government, prior to the large-scale implementation of RWH technologies, conducted a study/survey in most parts of the country and in some other countries having a longer RWH experience. This resulted in a "water harvesting technologies package" including household-based RWH systems providing water for humans, livestock and home garden horticultural crops (Desta, 2004). The RWH techniques most commonly practiced in Ethiopia are run-off irrigation (run-off farming), flood spreading (spate irrigation), *in-situ* water harvesting (ridges, micro basin *etc*.), roof water harvesting (Alem, 1999), birkas[1] in Somali region and different runoff basins in Konso (Amha, 2006) shallow wells (Soriano, 2007), Ella and Haffirs[2].

Like other regions, Oromiya regional state, especially at Central Rift Valley (CRV) has started the implementation of water harvesting technologies to overcome problems related to food security and poverty. Based on this, several RWH technologies have been constructed by the regional government, NGOs, communities, and individual farmers throughout the region within the last few years and more are planned. In 2002/2003, 83,400 ponds, 500 underground tanks and 6,100 hand dug wells were planned and 49% of the ponds, 102% of the underground tankers and 64% of the wells were completed in the same year (Chala *et al.*, 2003).

[1] Birka- A traditional way to harvest rainwater in Somalia region.

[2] Ella – A traditional deep water well in Borena zone.

Haffirs – An earthen embankment constructed with the aid of heavy machinery.

Different types of *in-situ* RWH have been used in different parts of Ethiopia. In Tigray, micro-basins (roughly 1 m long and < 50 cm deep) are often constructed along retention ditches for tree planting. The major conservation structures meant for erosion control commonly practiced in Ethiopia also conserve water *in-situ* and include soil bunds, stone bunds, *fanya juu* and grass strips (Alem, 1999). These are constructed in contour or graded depending on the rainfall of the area. For high runoff areas graded structures are used. In low rainfall areas of southern Ethiopia, farmers have developed a highly specialized water harvesting system. The cropland is prepared in multitudes of circular depressions (3-4 m in diameter and < 1 m deep) where a variety of crops are inter-cropped (Rämi, 2003). Tied ridging are traditionally used by small farmers in the eastern Hararghe area as in- situ RWH technique in sweet potato system using hand hoe (EARO, 2000).

2.4 Evaluation of RWH in Ethiopia

The implementation of thousands of RWH structure has been confined with a range of problems. Most people working in the field of RWH argue that most of the constructed RWH structures do not perform as planned. A number of studies have been conducted to evaluate the performance of the ambitious plan of the government to develop RWH. The studies were conducted by the government, NGOs or academia. Some studies assess financial benefit, some technical viability and others focused on assessing past experiences and identifying ways forward in order to facilitate Government policies. Many studies have indicated shortcomings in design and implementation of household RWH systems resulting in lower than expected performances and even the 'disadoption' by farmers (Tesfay, 2007; Segers *et al.*, 2008).

Ahmed *et al.* (2013) indicated that in situations where RWH technologies performance is poor, it's mainly due to decision makers placing too much emphasis on technology itself while ignoring farmers' own knowledge. The decision makers fail to recognize the processes by which farmers learn and adopt new practices. Thus poor performance of many RWH technologies in Ethiopia was partly explained by the improper selection of the targeted area with less suitable factors such as soil and rainfall. This was attributed to lack of proper planning, implementation and management. In most regions various authorities were involved during different phases of the implementation resulting in poor coordination and a lack of accountability. The planning and implementation approach was generally

top–down initiated by the national government with the ambition to show impact over large areas in a short period of time (Segers *et al.*, 2008; Haile, 2009).

According to the progressive evaluation report on the implementation of RWH in Oromiya (Chala *et al.,* 2003), 98% of sampled beneficiaries responded high seepage. The amount of collected water was not sufficient to meet the intended purpose according to 53% of the farmers in East Shoa and 22% in Welega. All the beneficiaries indicated that, the catchment for collecting runoff was sufficient but not the size of the RWH structure. The report concluded that, the status of the constructed ponds was not good owing to various problems like the unavailability of plastic sheet to reduce seepage losses, lack of coordination and facilitation during implementation, while community and land holding size were not taken into account during the design and implementation.

The evaluation of RWH ponds that were constructed in 2005 and 2006 in northern Ethiopia, Tigray, showed that the large majority failed because of insufficient water collection or leakage problems due to poor construction (Segers *et al.*, 2007). In addition, a considerable number of ponds suffered from lack of maintenance contributing to the poor performance. Some RWH ponds were silted up completely and remain as gentle depressions in the landscape. The other reason for failures was that households did not construct or maintain the diversion channels and inlets that are needed to harvest runoff water.

Similar conclusions were drawn by Alamerew (2006), who summarized the various constraints in implementing the RWH projects, including inadequate public awareness and ownership of local communities, lack of adequate knowledge and skills in management of RWH schemes, insufficient involvement of communities in planning and implementation processes and lack of facilitation for establishment/strengthening of Community-Based Organizations (CBOs). In addition, the author pointed out that the various RWH efforts lacked research. For example, on indigenous knowledge and best practices in RWH, improving traditional practices and/or adapting new technologies to local conditions which constitute among the critical inputs for a successful intervention.

Field assessments by the Oromiya Irrigation Development Authority (OIDA) identified problems with the implementation of RWH technology related to inefficient runoff collection and unwise use of the harvested runoff (Chala and Demissie, 2004). This is due to poor catchment selection and characterization in relation to the structure design and lack

of information on the utilization of the system (like family drip irrigation). The evaluation also collected opinions from non-target farmers (who don't have RWH), other OIDA staff and Development Agents (DAs) on to the issue "why RWH structures don't retain or hold water". The answer from the three groups pointed at high seepage losses attributed to either poor compaction, cracks in tanks, and poor site selection due to a lack of experience.

A RWH impact assessment at Alaba woreda showed a positive effect on agricultural productivity. The cropping pattern in the studied area changed and farm households started to grow cash crops which were not previously grown in the area. However, benefits depend on market and infrastructure access and crop diversification to minimize risk. Despite its potential, adoption of RWH technology is slow. Some reasons for the low adoption were poor quality of the construction resulting in cracks in the cemented floor and loss of water, improper site selection (insufficient runoff) and fear of malaria spread (Amha, 2006).

The RWH structures in Amhara and Tigray face many problems, many of which originate from the speed and scale of implementation (Rämi, 2003). Among the identified problems were (1) Poor site selection; it was done hurriedly and without experience, with the consequence that many tanks do not hold water. Often the level of poverty was used as the most important criteria for selection of target beneficiaries, while the technical criteria of runoff and water collecting potential were neglected. Poor site selection is the most important reason for failures. (2) Leakage; Most of the tanks (cemented) were leaking due to cracks in the walls of the structures. This was attributed to the lack of skilled labour during construction, the poor quality of work as result of the quota system imposed by the regional Government that put junior experts and development agents under pressure to construct tanks quickly. (3) Siltation and *(4)* Wastage and uneconomical use of water.

2.5 Sources of Water in Pastoralist Areas of Somali Region

Surprisingly, today the pastoralist areas are known for their drought, famine and dependency on food aid. Government regimes through history have never integrated them into the national economy; rather they were considered lawless and conflicts-ridden. The development of settlement and irrigation schemes in the name of modernizations which paralyze the dry and wet season's source of pasture and water was the outcomes of such mentality. The cumulative effect of the historical neglect, top down approaches, development of inappropriate technologies, poor marketing and extension system and

failure to appreciate the rationale behind pastoralism were attributing to the crisis in pastoral areas (Yohannes, 2002).

Apart from the available naturally bestowed rivers, the following are the major sources of water utilized at house hold level: -

i. Natural ponds: Usually natural ponds are located on depressions or concave slopes. The small ponds are locally known as Qayder and the relatively bigger ones are the Harro. Some of the ponds serve during the rainy season (Gu and Dayer) others serve few weeks in the dry season (Hagaya and Jelaal). There is no special water management and sanitations; all livestock enter to the water points. Consequently the trampled soil becomes very lose and easily washed out by wind and water to be deposited in the ponds.

ii. Locally made ponds: These are very old men made ponds, locally known as Balliyo even the pastoralists no longer know who originally excavated theme. Also small in number they are widely distributed in a range of 100 to 200kms thought Degahbour zone to prevent over concentration of animals in one spot and minimize also conflicts. Usually poor people who lost their livestock and temporally camp on such spots manage these water points. For the systematic serving of watering the animals the camel owners in return give them some milk. Still the system is functional but in a diminishing trend with the introduction of Birkas and Haffir dams (Yohannes, 2002).

iii. Earth dams: With the help of the government and some NGOs, some of the natural ponds were excavated by machinery in a semi-circle form all over Somali region. An observation in Aware camps and Gashamo area indicates that by and large such ponds are now silting up as they do not integrate the water management and catchments rehabilitation. Still such intervention is prevailing under emergency interventions by NGOs and government due to their inability to learn from past mistakes.

iv. Private Birkas: They are in-ground tanks lined with stone and concert, used to collect and store run-off rainwater for human and livestock consumption. In the Gashamo area it was introduced in the 1950s from the British colony and considerably increases in the 1970s following the drought and 1980s following the civil wars in Somalia and incoming refuges.

v. Haffir dam: Historically Haffir dam in Somali region was introduced from Sudan through UNHCR in the refugee camps of Aware. As of its original design it was meant to collect water only for human consumption. However, Hope for the Horn a local NGO closely working with pastoralists had been continuing to modify the technology by accommodating some of the feedbacks of the pastoralists. The Haffir dams made by machinery were to serve both livestock and human beings. The main dam and the silt trap were supplemented with outlet canal attached to two shallow wells where water is pumped to the elevated distribution cistern and further through gravity distributed to the livestock troughs and human collection points.

Currently there are a total of 17 Haffir dams constructed across the 400 kms, with an average distance of 60 kms from each other. These dams which serve as a blue (water) and green (fodder) belts cover the five districts of Gashamo (5 Haffir dams), Aware (5 Haffir dams), Harshen (3 Haffir dams), Kebrebehyah (3 Haffir dams) and Jigiga (1 Haffir dam). The spatial distribution of the blue and green belts is based on the consideration of different factors, such as the distribution of other sources of water (natural, tradational and Birkas), clan and sub-clan distribution, mobility patterns and reciprocity among the clans with territorial fluidity (Yohannes, 2002).

2.6 Methods and Tools Used for Identifying Sites Suitability for RWH

Rainfed agriculture is the predominant farming system in arid and semi-arid regions around the world, but aridity and climatic uncertainty are major challenges faced by farmers who rely on rainfed farming. Farmers are faced with low average annual rainfall and variable temporal and spatial rainfall distribution. To increase the availability of water for crop and livestock production, inhabitants of dry areas have constructed and developed several techniques for harvesting rainwater (Ziadat *et al.*, 2012). A water harvesting system should be chosen and designed for the local circumstances, taking into account the purpose of water harvesting, available funds, technical expertise, and the physical surroundings (Kato *et al.*, 2008).

A variety of methods can be used to integrate the different criteria into a tool for the selection of suitable sites for RWH. Since computer technology has advanced greatly in recent decades, GIS packages supported by remote sensing (RS) that offer cost-effective and

time-saving methods for identifying suitable sites for RWH. RS can be used to derive accurate information with high spatial and temporal resolution. For example, land-cover information and curve numbers (CNs), which are needed for runoff estimation, can easily be extracted in GIS environments. GISs are very useful tools, especially in areas where very little information is available, which is often the case in developing countries (Mahmoud and Alazba, 2014).

The use of geospatial technologies such as RS and GIS has been found to be effective tool for identifying suitable areas for RWH (Kahinda *et al.*, 2008; Jasrotia *et al.*, 2009; Jha *et al.*, 2014). GIS has been recommended for use in making decision during planning for RWH. In the recent past, the effectiveness of geospatial techniques in identifying potential sites for RWH has been reported by some researchers (Kahinda *et al.*, 2008; Mwenge Kahinda, Taigbenu and Sejamoholo, 2009; Weersinghe *et al.*, 2010).

Ziadat *et al.* (2012) applied a GIS approach for identifying the suitability for RWH interventions. They integrated bio- physical criteria such as slope, vegetation cover, soil texture, and soil depth with socio-economic parameters such as landowner and then modified the criteria. The data required for the biophysical criteria were obtained from various sources; contour lines extracted from topographic maps and slopes were derived from digital elevation models (DEMs). Arc GIS was then used to derive a slope grid and the grid was converted into polygons for use as land-mapping units in the analysis. A field survey provided other data for the biophysical criteria, such as soil texture/ depth and surface cover. The values for unmeasured locations were predicted using the inverse distance weight interpolator of ArcGIS 9.1.

De Winnaar *et al.* (2007) linked the SCS-CN method with a GIS to identify potential runoff-harvesting sites in a small sub-catchment in South Africa. This study provided a detail of the spatially explicit method and presented suitability maps for RWH sites. The Soil Conservation Service (SCS) method is the most widely used approach for estimating surface runoff from small catchments after a rainfall event. With this approach, the suitable locations for RWH structures were located in areas with the highest capacity for runoff generation and nearby to existing drainage lines (Kadam *et al.*, 2012). Similarly, Ahmad (2013) investigated potential RWH sites in Pakistan by studying the runoff pattern using a hydrological model with the GIS/RS approach. The Hydrologic Engineering Centre's

Hydrologic Modelling System (HEC-HMS) was used to simulate rainfall-runoff and to estimate runoff generation in each outlet of a sub-catchment.

Multi-Criteria Analysis (MCA) is a commonly used method of analysis that combines data for various criteria. One of the main rules of MCA is to estimate a relative weight for each criterion, rather than assuming the same weight for all criteria, and then compares two or more alternatives. The analytical hierarchy process (AHP) is an MCA tool that has been applied widely to identify potential RWH sites (Krois & Schulte, 2014; Munyao, 2010). Similarly, Krois and Schulte (2014) presented a method to identify suitable sites for RWH (terraces and bund systems) in the Ronquillo watershed in Peru by integrating MCA, SCS-CN, and a GIS.

2.7 Experiences in Rainwater Harvesting Vs GIS

For relatively small areas, a field survey carried out by experienced people will be the best technique to select the appropriate sites and to determine the suitable methods for rainwater harvesting. For larger areas the application of Geographic Information System (GIS) and Remote Sensing (RS) could be the most relevant means (Makhamreh, 2011). Similarly, for larger areas like Harshin District, ground survey is difficult and time consuming. The application of GIS can be helpful for a first screening and identification of areas potentially suitable for RWH.

Computer technology has advanced greatly in recent decades, including Geographic Information Systems (GIS) packages supported by Remote Sensing (RS). These offer cost effective and time-saving methods for identifying suitable sites for RWH (Ammar *et al.*, 2016). RS can be used to obtain accurate information with high spatial and temporal resolution. For instance, land-cover information and curve numbers (CNs), which are needed for runoff estimation, can easily be extracted in GIS environments. GISs are very essential tools, particularly in areas where very little information is available, which is often the case in developing countries (Mahmoud and Alazba, 2014).

United Nations Environment Programme (Mati *et al.*, 2006) conducted a study to determine if RWH technologies can be mapped at continental and country scales. The project utilized a number of GIS data sets including rainfall, land use, land slope and population density to identify four major commonly adaptable RWH technologies: roof top RWH, surface runoff collection from open surfaces into pans/ponds, flood flow storages

and sand/sub-surface dams and *in-situ* RWH. The identification of potential areas suitable for RWH is therefore the key for a successful RWH intervention. One of the main reasons for failure of RWH structures is the lack of scientifically verified information which could be used to identify areas where RWH can be applied and for which type of RWH techniques. The potential of areas for RWH depends on a multitude of parameters, either physical factors like rainfall, land use, soil and topography and/or the combination of the physical factors and socio-economic factors.

Kahinda *et al.* (2008) conducted a research in South Africa to develop tools and methodologies for RWH that not only assist planners with the identification of areas suitable, but also quantify the associated hydrological impacts of its wide scale adoption. Their study presented the rainwater harvesting decision support system (RHADESS) that was built to assist decision makers and stakeholders by indicating the suitability of RWH in any selected part of South Africa and quantifying the potential impacts associated with its adoption at catchment scale. RHADESS used was GIS-based and used Arc View 3.3 as a platform to assess the RWH suitability of any given area of South Africa. Results were thereafter exported into an Excel spreadsheet that contained the hydrological impact as runoff reduction of different levels of adoption of RWH assessed by using the Pitman model. The decision support system guided the implementation of the following RWH categories: Infield RWH and ex-field RWH and domestic RWH.

Gavade *et al.* (2011) conducted a study at Madha tahsil of Solapur district, India that was carried out by GPS, Survey of India topo-sheets *i.e.* NE 43-7 and NE 43-11, on scale of 1:250,000, SRTM data for creation of DEM and satellite imagery of LANDSAT ETM+ (30m spatial resolution). The criteria like third order stream, 2 to 3 degree slope of land, sandy-clay soil, 500 m settlement buffer zone was considered and various techniques of GIS and remote sensing were used for getting more suitable sites for rainwater harvesting.
Singh *et al.* (2017) conducted a study to present a technically robust and pragmatic methodology for evaluating rainwater harvesting potential and identifying suitable sites for RWH and artificial recharge structures using Geographic Information System (GIS)-based multi-criteria decision analysis (MCDA). The derived themes 'runoff coefficient' and the basic themes of 'slope' and 'drainage density' were used for mapping rainwater harvesting potential. Thereafter, suitable zones and sites for feasible RWH and recharge structures were identified using suitability criteria and GIS-based Boolean logic. Accordingly, the study area was divided into four RWH potential zones with 47% and 38% of the study area

falling under ‘high’ and ‘moderate’ RWH potential, respectively. The zones suitable for constructing farm ponds cover 2314 km^2 and those for percolation tanks on the ground cover 42 km^2. The integrated geospatial and MCDA approach is not only time saving and cost-effective but also very helpful for the efficient planning and management of rainwater at a larger scale.

Jha *et al* (2014) have presented a fairly robust methodology for evaluating RWH potential and identifying sites/zones for different RWH structures using geospatial and multi criteria decision analysis (MCDA) techniques. The remote sensing data and conventional field data were used to prepare desired thematic layers using ArcGIS© software. Distributed Curve Number method was used to calculate event-based runoffs, based on which annual runoff potential and runoff coefficient maps were generated in the GIS (geographic information system) environment. Thematic layers such as slope, drainage density, and runoff coefficient and their features were assigned suitable weights and then they were integrated in a GIS to generate a RWH potential map of the study area. Zones suitable for different RWH structures were also identified, together with suitable sites for constructing recharge structures (check dams and percolation tanks along the streams). It was found about 3% of the study area (30 km^2) is suitable for constructing farm ponds, while percolation tanks (on the ground) can be constructed in about 2.7% of the area (27 km^2). It was concluded that the integrated geospatial and MCDA techniques offered a useful and powerful tool for the planning of rainwater harvesting at a basin or sub-basin scale.

Naseef and Thomas (2016) showed that water harvesting is the best technique which can be used effectively to trap the unutilized surface runoff and thereby increase the groundwater recharge. But these structures have to be located at places where water is available in excess and conditions are favourable for enhanced infiltration with the objective of identifying suitable sites for water harvesting structures. ArcGIS was used for the spatial analysis and the sites were located by overlaying thematic maps of land use, soil, slope, runoff potential, soil permeability and stream order. It was found that 37 % of the total study area was ideal for constructing check dam, 7 % for farm pond, 4 % for percolation pond and about 2 % for subsurface dyke. Check dams were the most suited one and location for subsurface dykes was sparse. They added that, for the practical implementation of these structures, viability of other considerations such as economy, social implications, practical feasibility etc. need to be considered.

Another work (Ramakrishnan *et al.*, 2008) illustrated the efficacy of remote sensing and GIS tools for identifying suitable sites for check dams, percolation ponds, and subsurface dykes structures. Thematic layers such as land use/land cover, lithology, soils, slope, rainfall and drainage were generated using LISS-III, PAN (IRS-1D), Land-sat Thematic Mapper (TM) and collateral data. Runoff potential for different combinations of land use and hydraulic soil groups was computed and classified into three classes. A potential site suitability map for water harvesting/recharging structures was derived following an Analytical Hierarchy Process (AHP). The analytically derived potential site suitability map was validated in the field. The accuracy of prediction was estimated on the basis of proximity between derived and field validated sites.

Elewa *et al.,* (2012) mapped the potential of the Sinai Peninsula in Egypt for WH. A watershed modelling system was combined with a multi-criteria decision support system using 9 thematic layers related to catchment hydrological characteristics such as the volume of annual floods, drainage frequency, maximum flow distance basin slope and area. They found that between 5% and 12% of the catchment was considered highly suitable for WH while 64% was considered moderately suitable. This was despite the annual precipitation of the Sinai Peninsula being <100 mm/a in most areas, with only 5–15 rainfall days per year. They suggested that the criteria set out by many authors is too limited and that redefining the criteria used to assess the suitability of an area for WH may identify much greater potential for WH than most approaches predict.

Promotion of RWH in Ethiopia has given more emphasis on structural storage (*ex-situ* deep ponding) than *in-situ* RWH. However, *in-situ* RWH is preferred as it does not require water lifting from the pond and water application, is more closely linked to traditions, and the costs are lower (Desta, 2004). *Ex-situ* RWH is not suitable for staple crops such as cereals, which are needed by the farmers to secure their food needs as it is evaluated from cost benefit analysis. Mesfin (2004) also concluded that the most efficient and cheapest way of conserving water is *in-situ* RWH. Evaporation losses can be reduced greatly if rainfall is stored in the soil rather than in an open structure.

Different studies in Ethiopia showed the potential of different *in-situ* RWH methods to enhance soil moisture storage and rainfall use. Mesfin (2004) studied different *in-situ* RWH methods on soil water storage and on the growth, grain yield and water use efficiency of sorghum in the CRV and concluded that soil moisture increased compared to

conventional tillage methods. Temesgen (2007) showed that tied-ridging performed better in retaining water than the local tillage practice (with Maresha plow) and inverted broad beds (with broad bed maker) providing more water to crop production in a semi-arid region where rainfall is erratic. Girma (2009) in his study applied a GIS approach by integrating different factors such as, soil depth, soil texture, climate, land cover, slope and groundwater but did not include socioeconomic factors. Hence, socioeconomic factors (e.g. market access, infrastructure, population density) were recommended to be important for a complete assessment of the RWH land suitability.

2.8 Major Selection Criteria and Suitability Levels

Determining criteria to support a strategy for identifying suitable runoff harvesting sites requires a biophysical approach where information based on physically derived catchment characteristics is used for understanding the catchment's hydrological response. Such an approach is likely to save considerable amounts of the time that is required for identifying runoff harvesting sites given the availability of data (Winnaar *et al.*, 2007). The success of RWH systems depends heavily on the identification of suitable sites and their technical design (Al-Adamat *et al.*, 2012).

FAO (2003) as sited by (Kahinda *et al.*, 2008) lists six key factors to be considered when identifying RWH sites: climate (rainfall), hydrology (rainfall–runoff relationship and intermittent watercourses), topography (slope), agronomy (crop characteristics), soils (texture, structure and depth) and socio-economic (population density, work force, people's priority, experience with RWH, land tenure, water laws, accessibility and related costs). To develop a GIS-based RWH model that combines a Multi-Criteria Evaluation (MCE) process, Kahinda *et al.* (2008) used physical (land use, rainfall, soil texture and soil depth), ecological (ecological importance and sensitivity category) and socio-economic factors.

The selection of suitable sites for RWH depends on several criteria; two main groups of criteria, biophysical and socio-economic, have been defined (Mahmoud & Alazba, 2014). Ammar *et al.* (2016) in their study have identified three commonly prescribed sets of criteria (guidelines) for the selection of suitable RWH. The first set was proposed by the Integrated Mission for Sustainable Development (IMSD, 1995) and included only biophysical criteria. The second set was proposed by Oweis *et al.* (1998), who first included socio-economic

criteria. The third set was developed by FAO (2003) and included more criteria in both domains. Most publications since 2000 followed or were derived from one of these sets of guidelines.

Table 1: Commonly used guidelines to identify suitable sites for RWH.

Criteria	**Proposed Set of Criteria**		
	IMSD, 1995	**Oweis *et al.* (1998)**	**FAO (2003)**
Climate	Not defined	Rainfall	Rainfall
Hydrology	Drainage System	Drainage System	Rainfall-runoff relationship and intermittent watercourses
Topography	Slope	Slope	Slope
Agronomy	Land use land Cover	Land use land Cover	Crop Characteristics
Soil	Soil texture	Soil Type	Texture, structure and depth
Socio-economic	Not defined	Land Tenure	Population density, work- force, people's priority, experience with RWH, land tenure, water laws, accessibility and related cost

Adapted from Bulcock and Jewitt (2013).

FAO (2003) guidelines are presently the most comprehensive for the identification of potential RWH sites. They include more parameters and wider ranges relevant to RWH than the other guidelines and consider various socio-economic criteria more associated with the local farmers (Ammar *et al.*, 2016).

Soil

A water harvesting system should be chosen and designed for the local circumstances, taking into account the purpose of water harvesting, available funds, technical expertise, and the physical surroundings (Kato *et al.*, 2008). Moisture is assumed to be affected by soil type and slope of the area Therefore an area is considered suitable for RWH if it has soils with high water holding capacity such as clay loam while RWH is not suitable for areas that have shallow sandy soils due to low water holding capacity. This agrees with the study by Mbilinyi *et al.* (2014) that recommended RWH technologies to be implemented on soils with high water holding capacity.

The suitability of an area as a catchment area in RWH depends mostly on its soils characteristics. Soils with high infiltration rates, such as sandy soils, are not favourable for RWH technologies because large size of the soil particles determines how much rainwater can be stored in the soil profile. Bulcock and Jewitt (2013) explained that soil texture determines the total water storage of the soil, which determines moisture availability in *in-situ* RWH for crops during dry spells.

The soil depth must be deep enough to allow for excavation of RWH technologies as well as ensuring adequate rooting development and storage of the harvested water. The deeper the soil the higher is the water storage capacity and vice versa. Thus sites with deep soils are relatively suitable for location of 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 (Girma, 2009).

Topography

The slope of land is important in site selection and implementation of all ground based RWH systems, especially ponds, pans, weirs and also *in-situ* RWH (Mati *et al.*, 2006). A slope of the catchment affects how quickly water will runoff during a rain event. Msigwa *et al.* (2015) considered slope as a factor in their study. The slope of an area influences recharge and infiltration hence variation in amount of runoff is expected from the various terrains. A steep area will shed runoff quickly while a less-steep, flatter area will cause the water to move more slowly, raising the potential for water to remain on the soil surface (Alazba and Shereif, 2014). Farm ponds are generally more appropriate in areas having a rather flatter slope however a slight slope is needed for better harvesting of the runoff (Buraihi and Shariff, 2015). Therefore, flat areas with a slope less than 2% are assigned a higher suitability rank for *in-situ* RWH whereas for ponds areas with slope ranging from 2 to 8% are given higher suitability rank. Malesu *et al.* (2007) uses criteria, largely governed by the FAO standards, indicating that slopes of < 2% were best suited to most techniques of WH; however ponds could be situated on slopes up to 8%.

Land Use/Cover

Land cover properties also play an important role in runoff generation in that vegetative cover controls how much rainwater/surface runoff is intercepted, which directly influences the partitioning of water into infiltration and surface runoff. Different land uses results in different amount of runoff generated during rainfall. There is a correlation between the land cover and the runoff produced by a given area for a rainfall event (Jedhe, 2014).

The land use guidelines present many challenges; Singh *et al.* (2009) recommended land use classes such as shrub land, barren land or bare soils. These are often not used for agriculture, therefore suitable sites may be identified which are located far from where the water is needed. Water harvesting structures are often small and can be fitted within the farm lands/cultivated areas therefore to exclude this land use is restrictive.

Rainfall

The magnitude of rainfall plays a significant role in assessing the suitability of RWH for a given area. To account for the variability, FAO (2003) recommended the use of design rainfall of 67% probability of exceedance. The design rainfall is determined by means of a statistical probability analysis. For the design of water harvesting schemes, this method is as valid as any analytical method described in statistical textbooks. Promoting RWH in areas receiving less than 100 mm/year or more than 1000 mm/year of rains is not common or not recommended. There is hardly any productive water-based activity feasible in areas that receive less than 100 mm/year of rain; there is no incentive for to implement RWH schemes in areas with annual rains in excess of 1000 mm/year. Mwenge-Kahinda *et al.* (2008) used annual rainfall as one of the criteria for selecting potential areas for in-field RWH technologies.

Some practitioners and authors have amended the available guidelines to be more encompassing of local conditions. Al-Adamat *et al.* (2010) researched WH suitability in Jordan and ranked characteristics on a scale of 1 – 4 (with 4 being the most suitable) to develop a multi-criteria decision support system. Mean Annual Precipitation (MAP) was ranked with < 100 mm/annum being least suitable and > 500 mm/annum most suitable, slope < 3% most suitable while slopes > 10% least suitable, soils with clay content < 10% as least suitable and clay content > 35% most suitable. This allows marginal areas which may have only 2 of the 3 criteria regarded as suitable to be still be considered. For

example, an area with clay soils > 35% and a slope of < 3% but MAP of < 100 mm/a can still be ranked as suitable, even though not all the selection criteria have been meet.

2.9 Multi-Criteria Decision Making in GIS

It is generally assumed that Multi-Criteria Decision Analysis (MCDA) originated at the beginning of 1960s. Any decision-making process begins with the recognition of the problem to be decided. In the intelligence phase, a situation is examined for conditions calling for a decision. In the design phase, decision makers develop alternative solutions to the decision problem already identified. Typically, a formal model is used to support a decision maker in determining the set of alternatives. In the choice phase, decision makers evaluate the decisions and choose the best alternative (Drobne and Lisec, 2009).

Many Water Harvesting Techniques (WHTs) are available globally, so the selection of most appropriate techniques is often difficult. A simplified system of decision support can facilitate WHT selection and would create a better understanding amongst the stakeholders involved in the selection of most appropriate techniques. A GIS-based MCA, a key part of the approach, could be used to identify suitable locations for specific WHTs based on the developed database of WHTs and their suitability indicators (Schwilch *et al.*, 2009). Weighted overlay also known as Multi Criteria Evaluation (MCE) is the most commonly used GIS method of analysis that integrates data for several criteria. Malczewski (2004) in his study indicated that the use of Multi- Criteria Decision Making methods (MCDM) with GIS has considerably advanced the conventional map overly approaches to the land-use suitability analysis.

The bio-physical suitability assessment of WHTs in watersheds can be achieved by using multi-criteria analyses (MCA) embedded in geographic information systems (GIS). GIS-based MCA have been applied in various parts of the world to identify potential sites for WHT application (Saptarshi and Raghavendra, 2009; Singh *et al.*, 2009; Pandey *et al.*, 2011; Elewa *et al.*, 2012). Maps produced from suitability analyses deliver good spatial visualisation, provide an understanding of potentially suitable areas and can be presented and explained to the participants of a WHT selection workshop or decision makers.

As explained in Drobne and Lisec (2009) Weighted linear combination, or simple additive weighting, is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted

average. The decision maker assigns the weights of relative importance directly to each attribute map layer. The total score for each alternative is obtained by multiplying the importance weight assigned to each attribute by the scaled value given for that attribute to the alternative and then summing the products over all attributes. The scores are calculated for all of the alternatives and that with the highest overall score is chosen. The method can be executed using any GIS system with overlay capabilities, and allows the evaluation criterion map layers to be combined in order to determine the composite map layer which is output.

The methods can be implemented in both raster and vector GIS environments. Some GIS systems, e.g. Idrisi as explained by Eastman J. R. (2006), have built-in routines for the WLC method, and there are available freeware modules or scripts, e.g. for ArcGIS Boroushaki S. and J. Malczewski (2008) to perform that kind of MCDA of this sort. MCE is most commonly achieved by one of two procedures: The first involves Weighted Linear Combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average. The second is known as Boolean Overlay whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR).

With the weighted linear combination, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map:

$$S = \sum w_i x_i$$

Where S is suitability, W_i is weight of factor i, and X is the criterion score of factor i.

In cases, where Boolean constraints also apply, the procedure can be modified by multiplying the suitability calculated from the factors by the product of the constraints:

$$S = \sum w_i x_i \cdot \prod c_j$$

Where C_j is the criterion score of the constraint j. (Drobne and Lisec, 2009)

All GIS software systems provide the basic tools for evaluating such a model. In addition, in IDRISI, a special module named MCE has been developed to facilitate this process. However, the MCE module also offers a special procedure called an Ordered Weighted Average that greatly extends the decision strategy options available (Eastman J. R., 2006).

2.9.1 Criterion Weights

A wide variety of techniques exist for the development of weights. In very simple cases, assigning criteria weights may be accomplished by dividing 1.0 among the criteria. However, when the number of criteria is more than a few, and the considerations are many, it becomes quite difficult to make weight evaluations on the set as a whole.

There are four main groups of techniques for the development of weights (Malczewski, 1999):

→ **Ranking methods**, which are the simplest methods for assessing the importance of weights: every criterion under consideration is ranked in the order of the decision maker's preferences;

→ **Rating methods**, which require the estimation of weights on the basis of predetermined scale;

→ **Pair wise comparison methods**, which involve pair wise comparison to create a ratio matrix;

→ **Trade-off analysis methods**, which make use of direct trade-off assessments between pairs of alternatives.

We focus on a pair wise comparison method which has the added advantages of providing an organized structure for group discussions, and helping the decision making group focus on areas of agreement and disagreement when setting criterion weights. Breaking the information down into simple pair wise comparisons in which only two criteria need be considered at a time can greatly facilitate the weighting process, and will likely produce a more robust set of criteria weights. A pair wise comparison method has the added advantages of providing an organized structure for group discussions, and helping the decision making group hone in on areas of agreement and disagreement in setting criterion weights (Eastman, 2001).

The technique described and implemented in IDRISI is that of pair wise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). The first introduction of this technique to a GIS application was that of Rao *et al*. (1991), though the procedure was developed outside the GIS software using a variety of analytical resources. Analytic hierarchy process (AHP) is one of the GIS- based MCDM that combines and processes spatial data (Input) into a resultant decision (Output). Key steps in AHP as indicated by Malczewski (2004) include; (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for merging geographical data and decision maker's preferences into uni-dimensional values of alternative decisions. Thus AHP is a very important decision making tool that can be used to assist in obtaining an appropriate decision over suitability assessment of RWH.

The process illustrated by Saaty (2008) involves the identification of factors that are selected in a hierarchy manner starting from the overall goal to criteria, sub- criteria and alternatives. The research outlined four major steps in undertaking AHP organized in order to make a decision over alternatives. These were; (i) Definition of the problem to be considered, identify the goal which is the criteria that the other elements usually the alternatives will depend on which should be at the top of the decision making tree, (ii) develop a pair wise comparison matrix, (iii) Applying criteria to alternatives and rank alternatives, and (iv) Conduct sensitivity analysis by weighting. The weighing assigned to the thematic layer vary from one site to the other hence may not be replicated (Munyao, 2010).

Table 2- Saaty's Rating Scale (The fundamental scale of absolute numbers)

Importance	Definition	Explanation
1	Equal importance	Two elements have equal importance regarding the element in higher level
3	Week dominance	Experience or judgment slightly favours one element
5	Strong dominance	Experience or judgment strongly favours one element
7	Demonstrated dominance	Dominance of one element proved in practice
9	Absolute dominance	The highest order dominance of one element over another
2,4,6,8	Intermediate values	Compromise is needed

In developing the weights, an individual or group compares every possible pairing and enters the ratings into a pair-wise comparison matrix. Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half.

Where ever empirical evidence exists about the relative efficacy of a pair of factors, this evidence can also be used. The procedure then requires that, the principal eigenvector of the pair wise comparison matrix be computed to produce a best fit set of weights. If no procedure is available to do this, a good approximation to this result can be achieved by calculating the weights with each column and then averaging over all columns. Repeating this for each column and averaging the weights over the columns usually gives a good approximation to the values calculated by the principal eigenvector. In the case of IDRISI, however, a special module named Weight has been developed to calculate the principal eigenvector directly. It should be noted that these weights will sum to one, as is required by the weighted linear combination procedure (Eastman, 2001).

Since the complete pair wise comparison matrix contains multiple paths by which the relative importance of criteria can be assessed, it is also possible to determine the degree of consistency that has been used in developing the ratings. Saaty (1977) indicates the procedure by which an index of consistency, known as a consistency ratio, can be

produced. The consistency ratio (CR) indicates the probability that the matrix ratings were randomly generated. Saaty indicates that matrices with CR ratings greater than 0.10 should be re-evaluated. In addition to the overall consistency ratio, it is also possible to analyze the matrix to determine where the inconsistencies arise. This has also been developed as part of the Weight module in IDRISI.

2.9.2 MCE and Weighted Linear Combination

Some approaches and tools have been developed for appraising and selecting WHTs and for assessing the potential of WHTs at larger. A decision support tool was also developed to evaluate the success of out-scaling of some agricultural water management technologies at basin level (Schwilch *et al.*, 2009).

The weighted linear combination is the most commonly used decision rule in GIS-based land suitability analysis that is often applied in land use/suitability analysis, site selection, and resource evaluation problems because it is simple to understand and easy to apply within the GIS environment (Malczewski, 2000). A weighted linear combination is an analytical method that can be used when dealing with multi-attribute decision making or when more than one attribute must be taken into consideration. Every attribute that is considered is called a criterion. Each criterion is assigned a weight based on its importance. The results are multi-attribute spatial features with final scores. The higher the score is the more suitable the area would be (Drobne and Lisec, 2009).

The Weighted Linear Combination (WLC) aggregation method multiplies each standardized factor map (i.e., each raster cell within each map) by its factor weight and then sums the results. Since the set of factor weights for an evaluation must sum to one, the resulting suitability map will have the same range of values as the standardized factor maps that were used. This result is then multiplied by each of the constraints in turn to "mask out" unsuitable areas. All these steps could be done using either a combination of scalar and overlay, or by using the Image Calculator. However, the module MCE is designed to facilitate the process.

2.10 The Multi-Criteria/Multi-Objective Decision Support Wizard

In situation when the benefits of actions are unpredictable, when relationships between variables may be not only non-linear and stochastic but also actually unknown, the principle of optimisation for decision-making will not help much. The problem can be abstracted as how to derive weights, rankings or importance for a set of activities according to their impact on the situation and the objective of decisions to be made. This is the process of multiple-criteria decision-making (MCDM). The MCDM problems have been studied under the general classification of operations research (OR) problems, which deal with decision-making in the presence of a number of often conflicting criteria (Saaty and Vargas, 2001).

The object is to use the weights which we call priorities, for example, to allocate resource among the activities or simply implement the most important activities by rank if precise weights cannot be obtained. The problem then is to find the relative strength or priorities of each activity with respect to each objective and then compose the result obtained for each objective to obtain a single overall priority for all the activities. Frequently the objectives themselves must be prioritized or ranked in terms of yet another set of (higher-level) objectives. The priorities thus obtained are then used as weighting factors for the priorities just derived for the activities (Saaty, 1977).

With Idrisi 32 Release 2, a wizard (set of linked dialogs) was added to the system to help guide users through multi-criteria/ multi-objective resource allocation procedures like those illustrated above. The wizard steps the user through each phase of building the full model and records the decision rules in a file that can be saved and later modified. A special section of the help system provides additional information for each wizard screen. Novice users will find the wizard helpful in organizing their progress through the sequence of steps while advanced users will appreciate the ability to save a full MCE/ Multi-Objective Land Allocation (MOLA) model that can be altered and run repeatedly to produce alternative final allocations. The wizard is launched from the Analysis/Decision Support menu (Eastman, 2001).

3. MATERIALS AND METHODS

3.1 Description of Study Area

Somali Region (SR) is one of Ethiopia's largest regions located $7^0$26´19´´N and $44^0$17´49´´E. It covers a total of 317,725.12Km^2 area. There are nine administrative zones in SR: Afder, Doolo, Fafan, Jarar, Korahe, Liben, Nogob, Shebelle and Siti. Among these zones, Fafan zone has six weredas (districts) namely: Awbere, Babille, Gursum, **Harshin**, Jijiga and Kebribeyah. Harshin, the study area, is located about 127 Km east of Jijiga town. Harshin is bordered on the south by the Degehabur zone, on the west by Kebribeyah and on the east by Somalia. Harshin woreda is composed of 30 Kebeles; the major town in Harshin is Harshin.

Harshin District is found approximately 730km far from the capital city of Ethiopia, Addis Ababa. Its Geographic location is 9° 13' 0" North & 43° 35' 0" East. It covers a total area of 4,309.0km^2. Its altitude range from 1,302 to 1,700m above sea level and it receives annual rainfall that fall from 200 to 600mm. The area has a semi-arid climate. The temperature ranges from 25-29°C with average temperature of the 27°C (Fikru, 2015).

According to CSA (Central Statistical Agency) 2008, the study area has estimated total population of 80,244 of which 43,869 are men and 36,375 are women. About 90% of the district communities dwell in the rural area and depend mainly on livestock production for their livelihood while 10% of the populations are urban and suburban dwellers. 99.39% of the populations are Muslim (Melat and Zinabu, 2012).

The water resource in the district is scarce and with erratic nature. Traditionally, the people in Harshin district store the only available source of water, rain water, in cisterns (known as Birkas) for domestic as well as livestock consumption. Water supply in Harshin is 100% surface water system through rain water harvesting. Run-off water from rainfall is directed and filled into dug cemented structures called Birkas. People in all Kebeles depend on surface rainwater harvesting both for human and livestock consumption. There are a total of 3,503 Birkas in the District, of which 69% are functional (Melat and Zinabu, 2012).

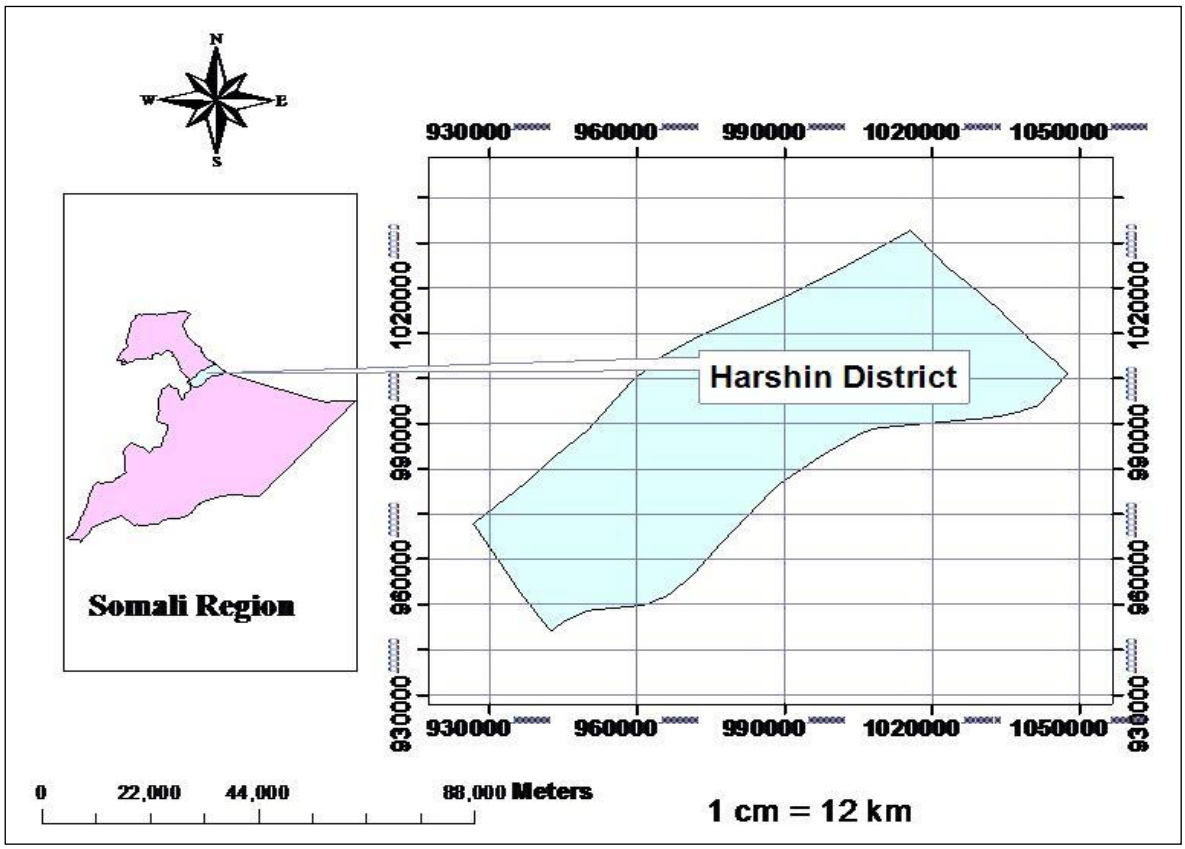

Figure 2: Location of study area, Harshin District.

3.2 Methodology of RWH Potential Mapping

The general approach of this study was to map potential/ suitable areas for pond RWH interventions in Harshin district. According to Saaty (2008), multi-objective multi-criteria methodology that is followed for this study involves mainly the following major steps:-

1. Selection of criteria,
2. Assessment of suitability level,
3. Assignments of weights to the selected criteria,
4. Collection of spatial data for the criteria using GIS tools,
5. Developing a GIS-based suitability map which combines maps through Multi Criteria Evaluation (MCE) process and finally,
6. Generating suitability map.

3.2.1 Criteria Selection and Assessment of Suitability Level

From the literature review and the availability of data in the region/zones, four criteria were used for the identification of pond RWH potential areas of Harshin District: soil type, rainfall, topography (Slope) and land cover. Because of the different scales on which the criteria are measured, MCE requires that the values contained in the criterion map are converted into comparable units.

Accordingly, the criteria maps were re-classed into five comparable units *i.e.* suitability classes and ranked with numbers 1 to 5 as: 5 (very high suitability), 4 (high suitability), 3 (medium suitability), 2 (low suitability) and 1 (very low suitability). The suitability classes were then used as base to generate the criteria maps (one for each criterion). This ranking system was selected because it has been used in many studies (Mwenge Kahinda *et al.*, 2008; Singh *et a.l*, 2009; Girma, 2009; Munyao, 2010) and it has been found to be a vigorous and a reliable method (Mahmoud and Alazba, 2014).

3.2.1.1 Soil Texture

Farm ponds are suitable in areas with low soil permeability. Therefore, finding suitable areas for ponds in this study area should be able to focus in locating areas with good potential in retain the harvested water. Clay soils have low permeability (high hydraulic resistance) and can hold the harvested water, and therefore they are the best soils for water storage (Bulcock and Jewitt, 2013).

Regarding *in-situ* RWH, soils with high water holding capacity are suitable for ridges and borders (*in-situ*) where as sandy soils are not suitable (Mbilinyi *et al.*, 2014). Therefore loamy soils are most suitable for *in-situ* RWH whereas clay soils are less suitable because of their low infiltration capacity and risk of water logging.

In order to generate Harshin District soil textural map, the layer was clipped from Somali Region land suitability dataset generated in 2013 for the whole Ethiopia obtained from Ethiopia Mapping Agency (EMA) which was described in figure 3 below.

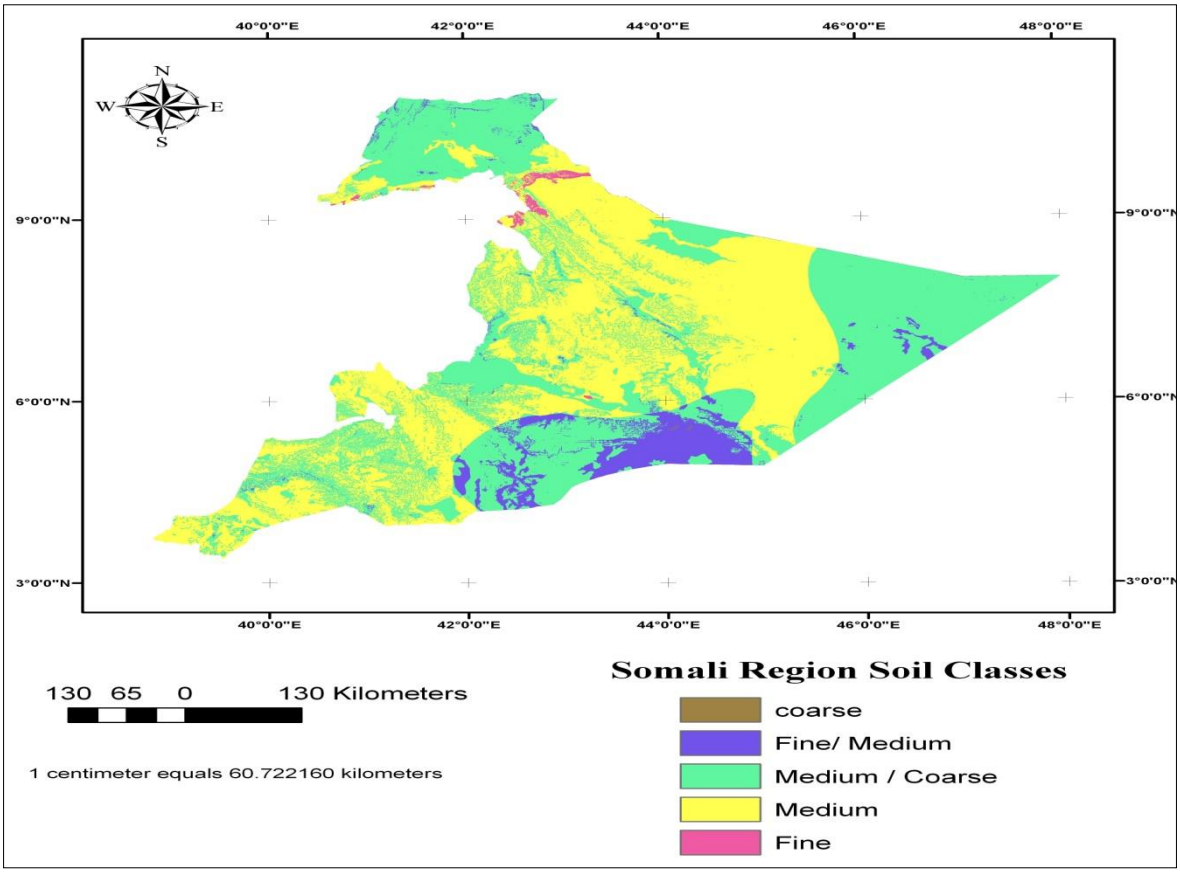

Figure 3: Somali Region soil textural map.

Then the soil textural map of the Harshin District was clipped from Somali Region soil map dataset. The land type dataset was finally reclassified into five soil textural classes: Loamy sands to sands, Sandy loams, Sandy clay loam, Sandy clays and Clays (Table 3).

Additionally, thirty disturbed soils sample at the depth of 30-60cm one from each kebele of Harshin District were collected. The soil sampling was made near the constructed ponds both from full and empty ones with a GPS reading taken at the sampling site. This intern could be used for cross-checking and validation purpose. The collected samples were analyzed texturally using sieve and pipette method at Haramaya University soil lab as presented in Appendix Table-1. Each textural class was then reclassified following the FAO (2003) soil texture triangle, which indicates the relative proportion of sand, silt and clay suitable for RWH. The collected soils result were included in the attribute table of Harshin District soil map for further refinement and better ground related result achievement.

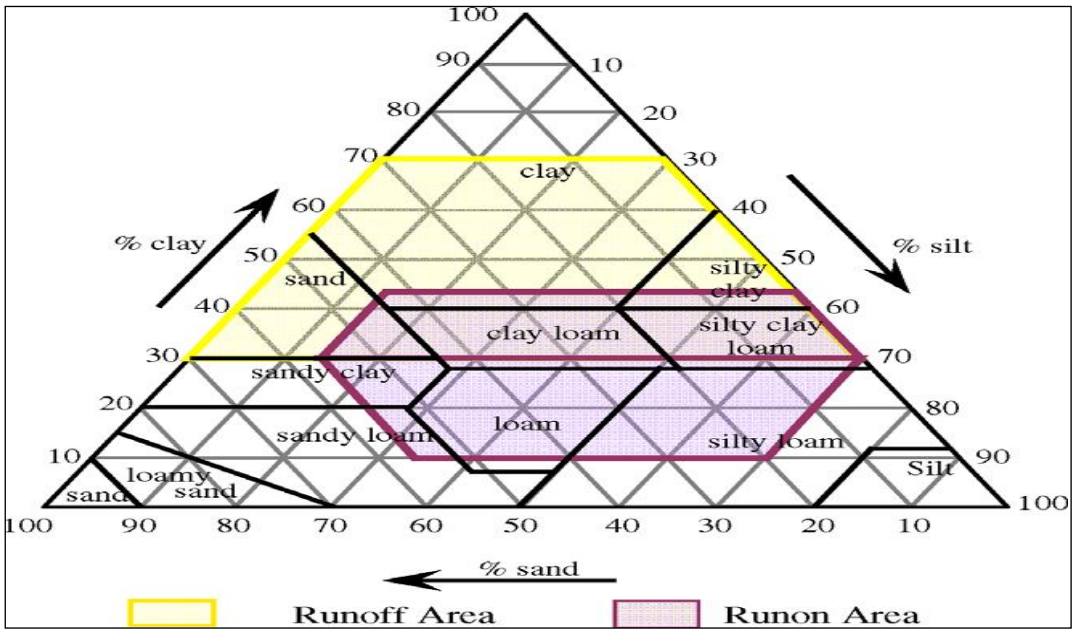

Figure 4: Soil texture triangle (FAO, 2003).

Table 3: Suitability rank for soil texture

No.	Soil textural class	Pond
1	Loamy sands to sands	2-1
2	Sandy loams	3
3	Sandy clay loam	4
4	Sandy clays	5
5	Clays	3

Source: Kahinda *et al.*, (2008)

3.2.1.2 Rainfall

For a water harvesting planner, the most difficult task is to select the appropriate design rainfall according to which the ratio of catchment to cultivated area will be determined. Design rainfall is defined as the total amount of rain during the cropping season at which or above which the catchment area will provide sufficient runoff to satisfy the crop water requirements. If the actual rainfall is below the design rainfall, there will be moisture stress; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to the structures (FAO, 2003).

The magnitude of harvestable rainfall plays a significant role in assessing the suitability of RWH for a given area (Kahinda *et al.*, 2008). Promoting RWH in areas receiving less than 100 mm/year or more than 1000 mm/year of rain is not common or not recommended (FAO, 2003; Al-Adamat *et al.*, 2010). Therefore, for this study, a design rainfall of 67% probability of exceedance was set.

In order to generate Harshin District rainfall map, the rainfall layer that was clipped from Somali Region rainfall dataset obtained from Ethiopian Mapping Agency (EMA) dated 2013 was used as one input.

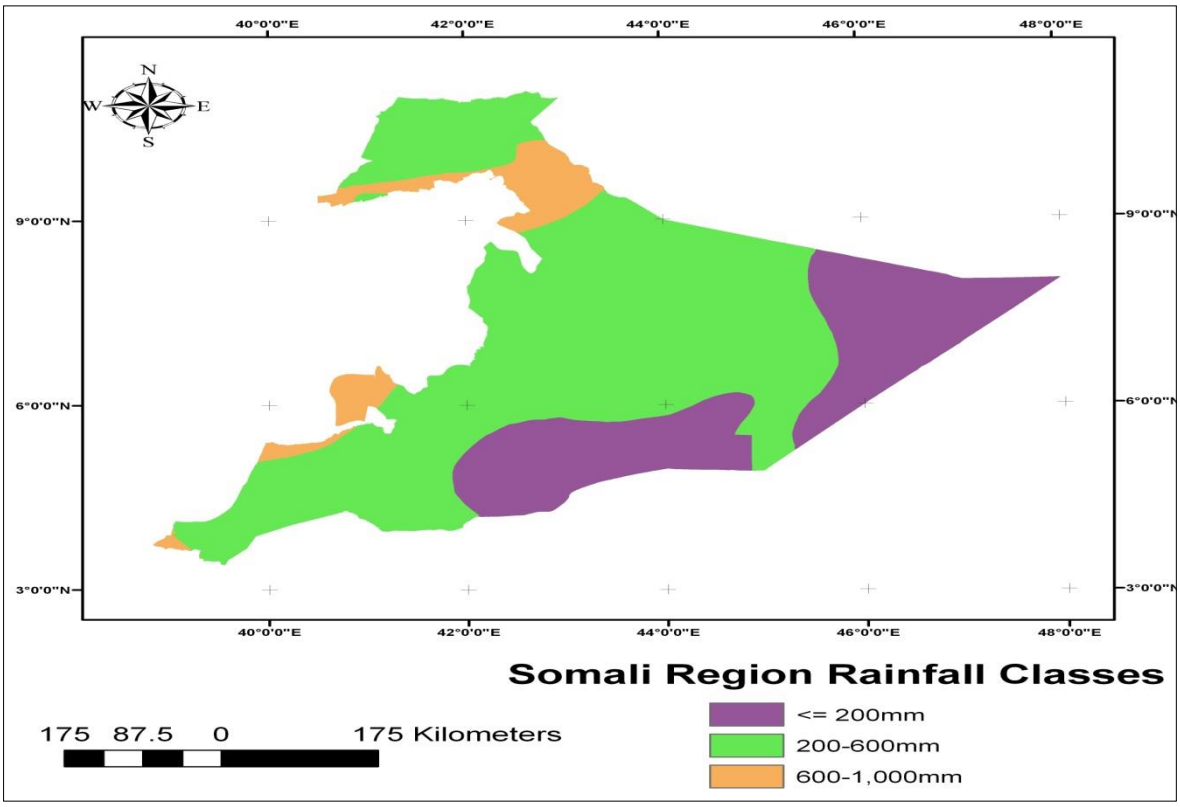

Figure 5: Somali Region rainfall map.

Further, in location like Harshin District of SR, where rainfall records do not exist, figures from stations nearby were used with caution. Long-term records of 35 years annual rainfall data from six stations were used for interpolation that was officially bought from Ethiopia Meteorology Station presented in Appendix Table-2.

Before using rainfall records of stations that were collected from National Meteorology Agency for any analysis, the data were checked for continuity & consistency and missing rainfall data were estimated using the rainfall data at neighbouring stations.

As per FAO (2003), a graphical method to determine the probability or frequency of occurrence of yearly rainfall was utilized. For the design of water harvesting schemes, this method is as valid as any analytical method described in statistical textbooks (Critchley *et al.*, 1991). The available 35 years rainfall data of the area was used for this analysis. Procedurally, the annual totals where ranked with m = 1 for the largest and m = 35 for the lowest value and the data were rearranged accordingly. Then the probability of occurrence P (%) for each of the ranked observations was calculated using equation:

$$P(\%) = \frac{m - 0.375}{N + 0.25} \times 100$$

This equation is recommended for N = 10 to 100 (Reij *et al*, 1988).

Where:

P = probability in % of the observation of the rank m
m = the rank of the observation
N = total number of observations used

Then the ranked observations were plotted against the corresponding probabilities as presented in Appendix Table-3 to Table-5. For this purpose normal probability paper was used and finally, a straight line was fitted to the plotted observations in such a way that the distance of observations above or below the line could be as close as possible to obtain the probability of occurrence or exceedance of a rainfall value of a specific magnitude. Inversely, it is also possible to obtain the magnitude of the rain corresponding to a given probability. This was presented in Appendix Figure 1 to 6; thus, it was possible to obtain the probability of occurrence or exceedance of a rainfall value of a 67%.

For this study, generation of a spatial distribution of the rainfall is done by using the Inverse Distance Weight (IDW) interpolation method of ArcGIS. Thus, by combining the two inputs, reclassification and ranking was made (table-4) where high suitability rank was given for areas with larger rainfall values as it ensures the availability of runoff to be harvested.

Table 4: Rainfall suitability ranking

No.	Rainfall (mm) perAnnum	Pond
1	0-100	1
2	100-200	2
3	200-400	3
4	400-600	4
5	600-800	5
6	800-1000	3
7	>1000	1

Source: Kahinda *et al.* (2008)

3.2.1.3 Topography/ Slope

Other important requirement to be considered in the implementation of water harvesting systems is the slope of the area and operation costs. Such rainwater harvesting techniques are not recommended for areas where slopes are greater than 5 %, due to uneven distribution of runoff and large quantities of earthwork required which is not economical (Critchley *et al.*, 1991). The slope of land is important in site selection and implementation of all ground based RWH systems, especially ponds, pans, weirs and also *in-situ* RWH (Mati *et al.*, 2006).

In order to generate Harshin District slope map, the layer was clipped from Somali Region topographic map dataset derived from the DEM elevation dataset with 90m resolution obtained from Ethiopian Mapping Agency (EMA).

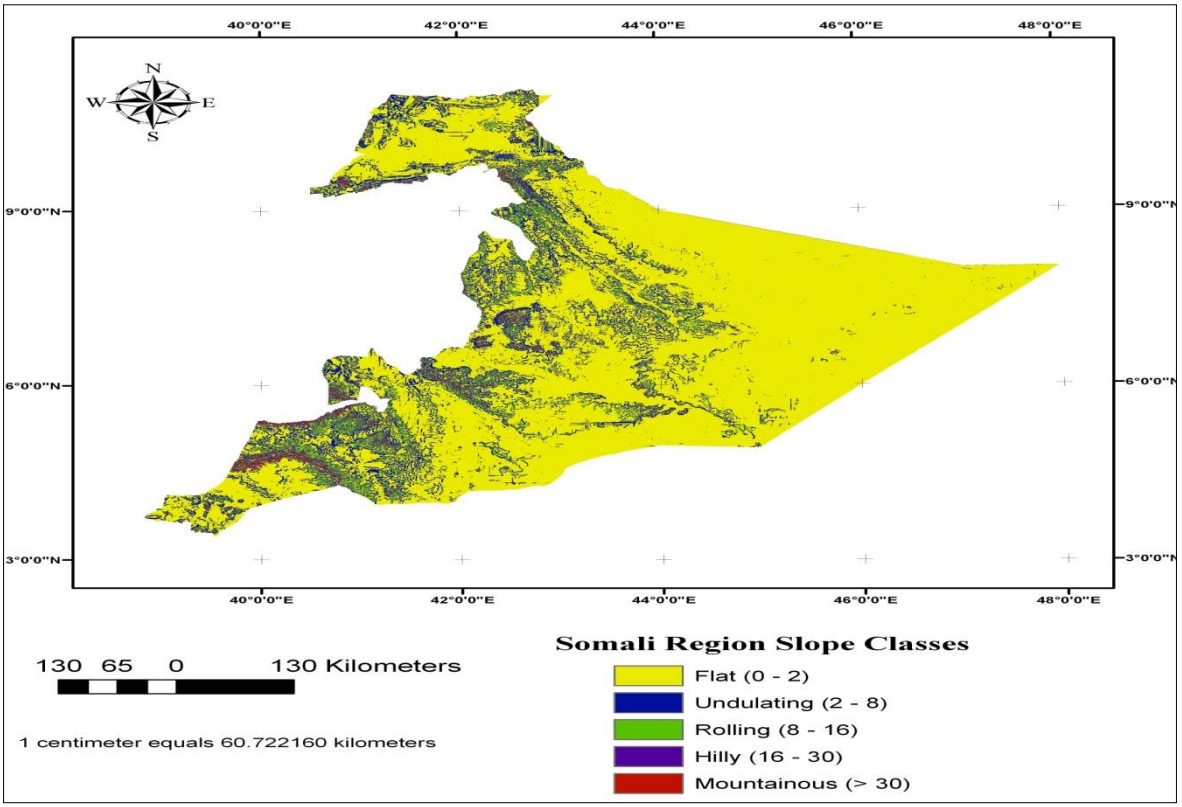

Figure 6: Somali Region slope map.

For this research, a slope map, expressed in percentage, for Harshin District was derived from the DEM elevation dataset with 90m resolution obtained Somali Region slope map. The attribute table of the topo map of the study area was enriched with the additional digitized data through GPS readings that were taken at the time of soil sampling. Accordingly, by combining the two inputs, the map was re-classified reclassified into five classes based on IMSD Guidelines namely: 0-2% is flat; 2-8% is undulating; 8-16% is rolling; 16-30% is hilly; > 30% is mountainous and assigned different suitability rank for ponds & *in-situ* RWH and analyzed for this research (Table 5).

Table 5: Suitability rank for slope

No.	Slope classes	Slope (%)	Pond
1	Flat	< 2	3
2	Undulating	2 - 8	5
3	Rolling	8 - 15	4
4	Hilly	15 - 30	2
5	Mountainous	> 30	1

Slope categories as per IMSD Guidelines.

3.2.1.4 Land use/cover

Vegetation/ tillage operation strongly influences the water harvesting systems on the infiltration, crusting, runoff and erosion processes. By interception and evaporation, the vegetation reduces the amount of rainfall reaching the ground. On the other hand, its presence breaks the impact of raindrop, which reduces soil erosion to about one percent of its value on bare soil and minimizes the crusting formation. Straw mulch, roots, litter and other crop residues reduce the velocity of runoff; as a consequence there is a large difference in terms of infiltration rates between bared soils and soils covered with any type of vegetation. Infiltration rates below grass tuffs appeared to be 5-10 times higher than between tuffs in open grassland (Reij *et al.*, 1988).

The land cover map of Harshin District was clipped from land use/cover dataset of Somali Region obtained from EMA. Additionally, the land use/cover of Harshin District was analyzed from the aerial photo as well as the existing land use map of the region and was cross-checked using GPS & ground observation. The land cover map was reclassified and assigned numeric values by combining the above inputs (Table 6).

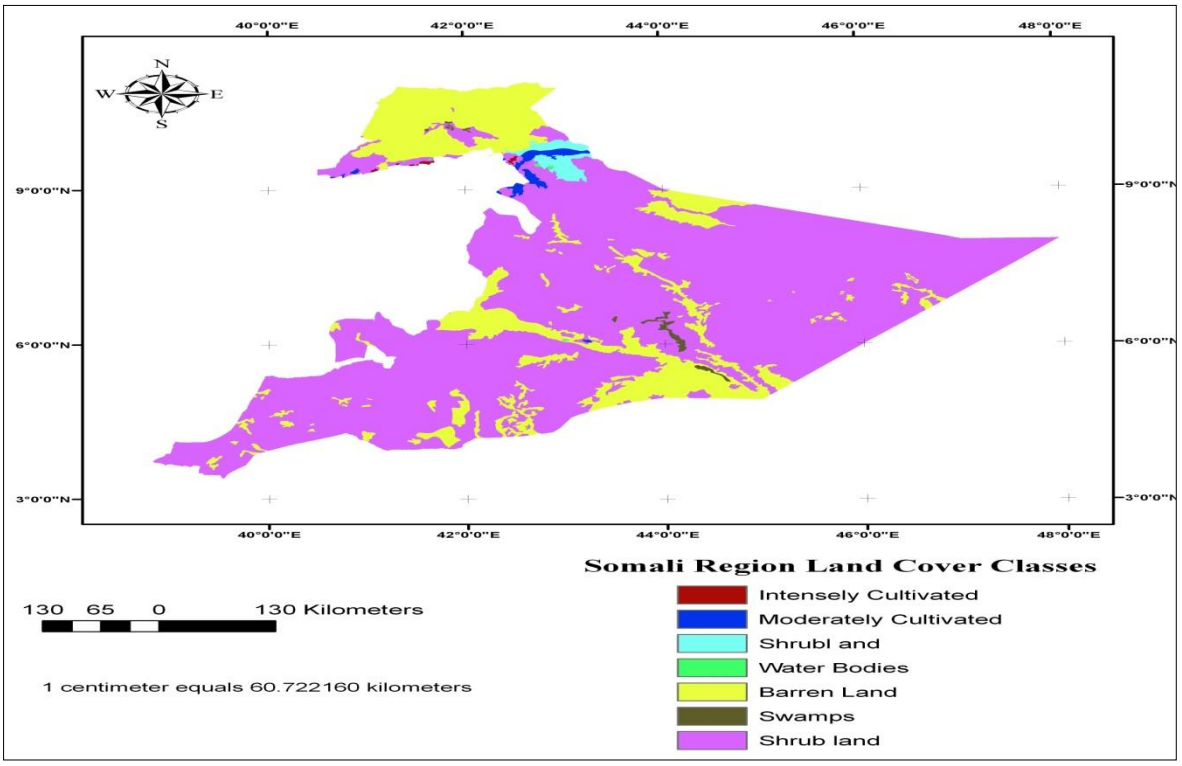

Figure 7: Somali Region land use/cover map.

Table 6: Suitability rank for land cover

No.	**Land cover class**	**Land cover types**	**Pond**
1	Very High	Intensively Cultivated	5
2	High	Moderately Cultivated	5
3	Medium	Forest, Exposed Surface	2
4	Low/ restricted	Mountainous	2
5	Very Low/restricted	Water body, urban area	restricted

Source: Girma Moges (2009)

3.2.2 Establishing the Criteria Weights

Since not all the criteria are equally important for the identification of potential RWH areas, different weights were assigned to the criteria. For the development of weights, the pair-wise comparison known as the Analytical Hierarchy Process (AHP) developed by Saaty (1977) was used. Pair-wise comparison concerns the relative importance of two criteria involved in determining the suitability for a given objective.

The method Analytic Hierarchy Process (AHP) is mathematically simple matrix based technique, but it is also powerful decision supporting tool. The best description of this method is probably the one given by Forman (*1983*); AHP is a compensatory decision methodology because alternatives that are efficient with respect to one or more objectives can compensate by their performance with respect to other objectives.

AHP is composed of several previously existing but non-associated concepts and techniques such as hierarchical structuring of complexity, pair-wise comparisons, redundant judgments, an eigenvector method for deriving weights, and consistency considerations. Although each of these concepts and techniques were useful in and of themselves, Saaty's synergistic combination of the concepts and techniques (along with some new developments) produced a process whose power is indeed far more than the sum of its parts.

According to Saaty (2008) to make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared. In Saaty's technique, weights of this nature can be derived by taking the principal eigenvector of a

square reciprocal matrix of pair wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved in determining suitability for the stated objective. Ratings are provided on a 9 - point continuous scale.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	**Very Strongly**	**Strongly**	**Moderately**	**Equal**	**Moderately**	**Strongly**	**Very Strongly**	**Extremely**
Less Important					**More Important**			

Figure 8: The Continuous Rating Scale by Saaty (2008).

In this Thesis, the measurement tool for the pair wise comparisons of all selected parameters of RWH was done by assignment of weights to each parameter as shown in table 7. Next, a comparison matrix was created using the results from AHP. This was done by incrementally in a rank-order (starting with the most important factor) and numerical weights were computed using the rank sum value method. Starting with the diagonal values which are always one (1). Priority vector is also called normalized principal Eigen vector/ weight (Saaty, 2008). To normalize the values, the cell value was divided by its column total. And to calculate the priority weight, the mean value of the rows was determined. The weight calculation requires the computation of the principal eigenvector of the pair-wise comparison matrix to produce a best-fit set of weights. For this calculation the WEIGHT module of Idrisi software was used and the result is summarized in Table 8.

Finally, the accuracy of pair wise comparison in this study was validated by calculation of the consistency index (CI). The consistency index which is a measure of deviation from consistency basing on the comparison matrix is expressed as:

$$CI = (\lambda - n) / (n - 1)$$

Where ƛ is average value of consistency vector and n is the total number of columns in the matrix (Saaty, 2008).

Then the consistence ration (CR) was calculated using the formula:

$$CR = CI / RI$$

Where random index (RI) is an index that depends on the number of elements that are being compared Saaty (2008).

Random Index (RI) Saaty, 2008.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The Consistency Ratio (CR) of the matrix, which shows the degree of consistency that has been achieved during comparing the criteria or the probability that the matrix ratings were randomly generated, was 0.04 for pond, which is acceptable as the values are less than or equal to 0.1 (Saaty, 2008).

Table 7: Pair-wise comparison matrix for ponds.

	Texture	**Rainfall**	**Land use/ cover**	**Topography**
Texture	1	3	6	5
Rainfall	1/3	1	4	3
Land use/cover	1/6	1/4	1	1/2
Topography	1/5	1/3	2	1

Table 8: Weight (Percent of Influence).

No.	**Criteria**	**Weights (%) Ponds**
1	Texture	40
2	Rainfall	30
3	Land use/cover	20
4	Topography	10
	Sum	**100**

3.3 GIS Database

The GIS dataset of the criteria required for the identification of suitable areas were derived from available data sets, most of it collected from regional/federal agricultural bureau, water bureau, National Meteorology Station and ground observation. The GIS database required for identifying RWH potential areas were developed using ArcGIS software, by utilizing both vector and raster databases.

3.4 GIS Analysis

Generating suitability map was done using a suitability model builder of ArcGIS 9.1. The suitability maps for RWH were generated by integrating different input criteria maps using Weighted Overlay Process (WOP) also known as Multi-Criteria Evaluation (MCE). MCE can be achieved by a Weighted Linear Combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average. WLC, criteria were combined by applying a weight to each followed by a summation of the results to yield a suitability map using the following equation (Saaty, 2008):-

$$S = \sum w_i x_i$$

Where S = Suitability
w_i = weight of factor $_i$
x_i = criterion score of factor $_i$

Therefore the higher the suitability value (*S*) of a given site (pixel) *i*, the more suitable the pixel is for RWH technologies. S is based on the established suitability ranking of 1-5 where 1 denotes the areas (pixels) that are not suitable and 5 indicates areas (pixels) that are very highly suitable for RWH (De Winnaar *et al.*, 2007). All GIS software systems can provide the basic tools for evaluating such model. Additionally, in IDRISI, a special module named MCE has been developed to facilitate this process.

3.5 Data-Action Modeling

The logical formal data model defines which input datasets are used in an application and in which order. It also specifies all successive geo-processing steps that have to be carried out on the input datasets. Finally, the logical formal data model lists the output datasets; these include not only the end result(s) but also the intermediate results (output datasets from various geo-processing steps that are used as input for the next processing step). A formal presentation of a logical data model can be in form of a data-action model. A data-action model gives a structured overview of the methodological framework to solve a spatial problem, in form of a flow chart.

The following were the detail flow chart used for suitability mapping of pond RWH potential in Harshin District of Somali Region: -

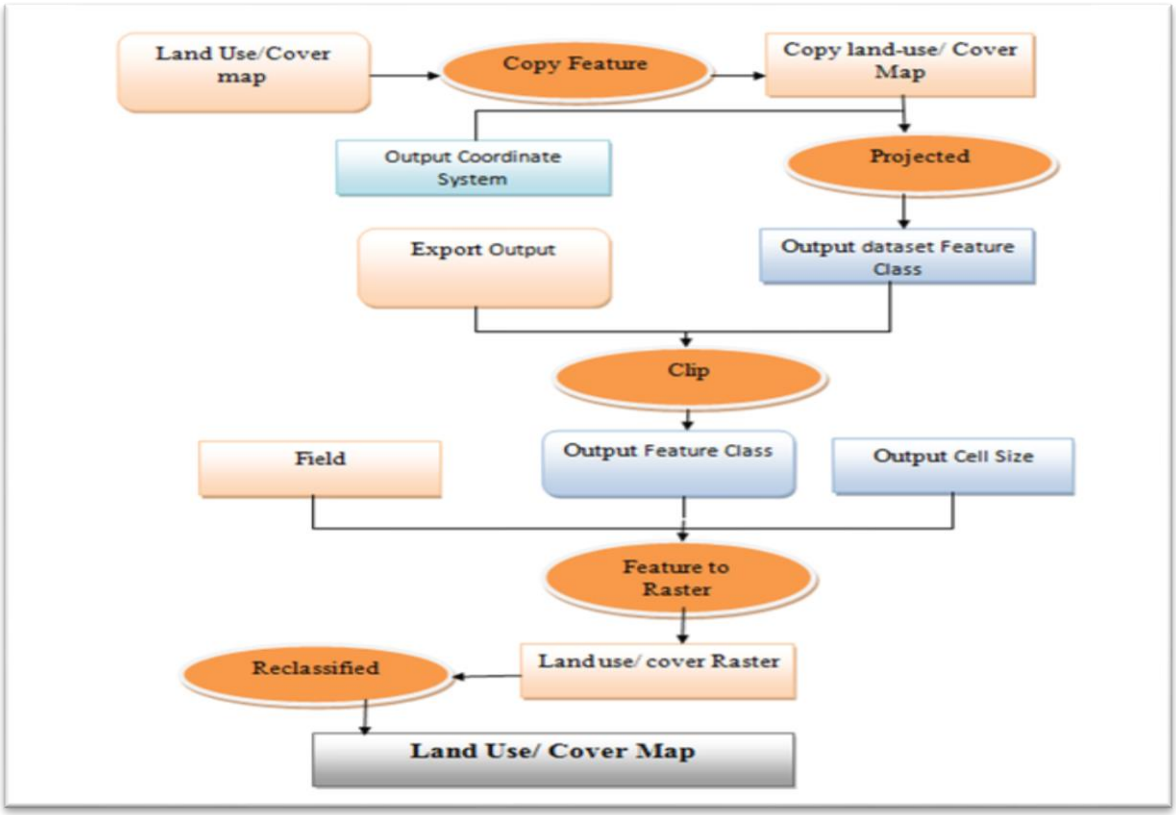

Figure 9: Detail flow chart for land use/cover mapping in ArcGIS.

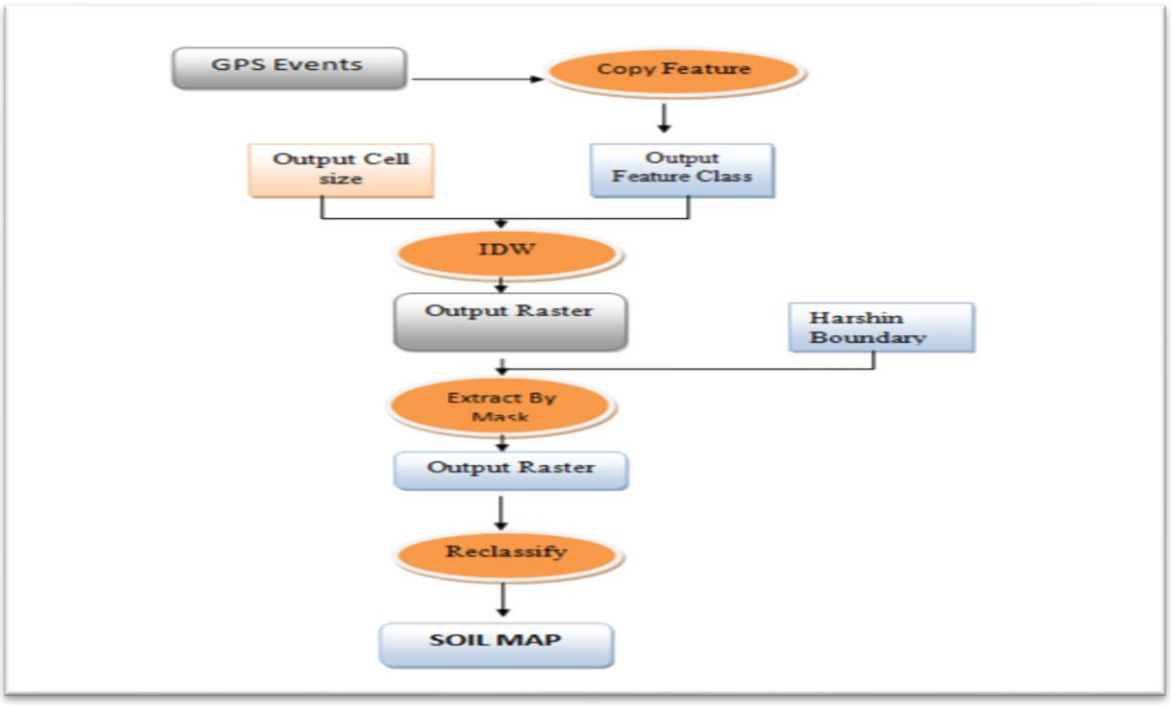

Figure 10: Detail flow chart for soil mapping in ArcGIS

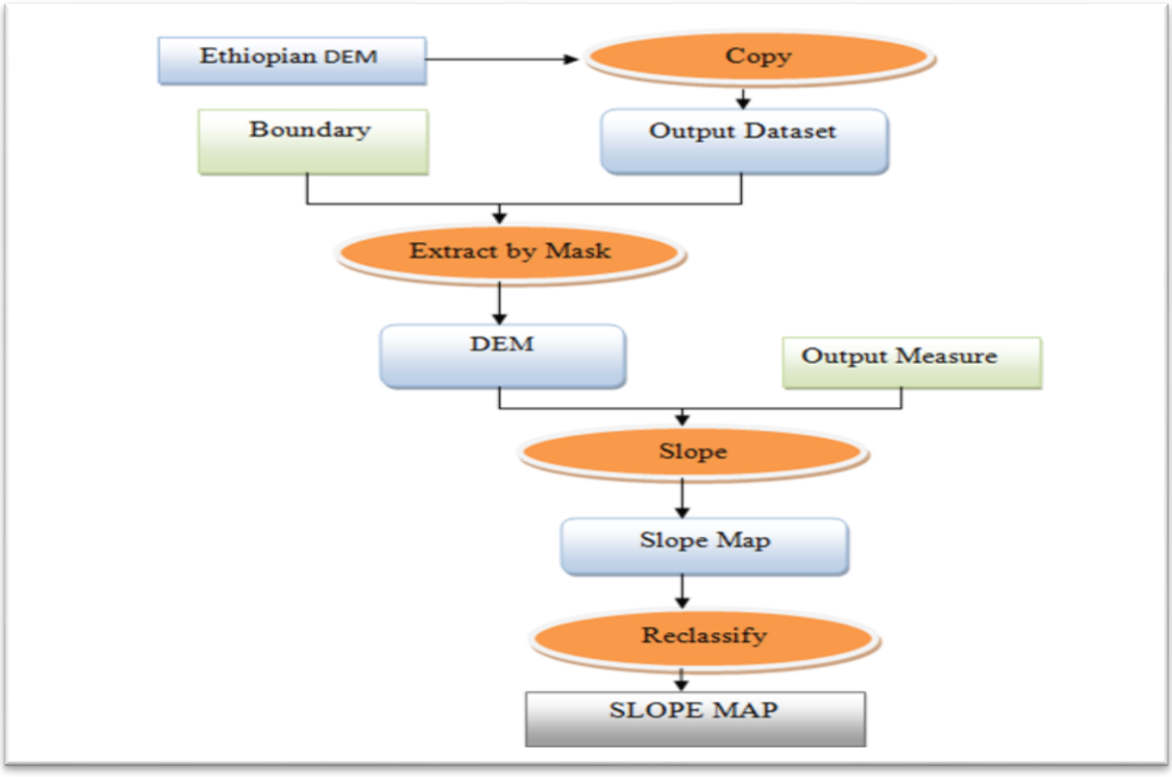

Figure 11: Detail flow chart for slope mapping in ArcGIS

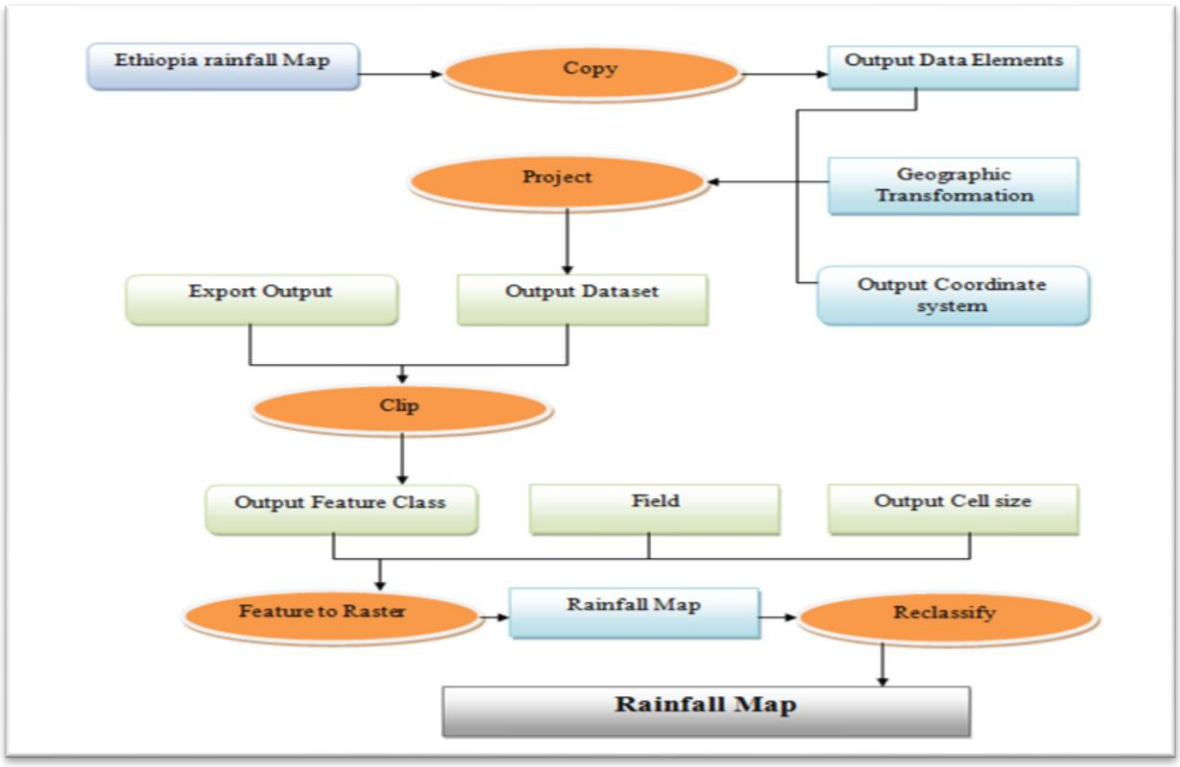

Figure 12: Detail flow chart for Rainfall mapping in ArcGIS

3.6 Validation and Testing

Validation of the suitability maps was done by cross-checking the suitability map with existing RWH structures. Global positioning system (GPS) readings were taken on existing RWH structures and incorporated in the ArcGIS environment for analysis. During the GPS survey, readings were taken from both successful and unsuccessful interventions.

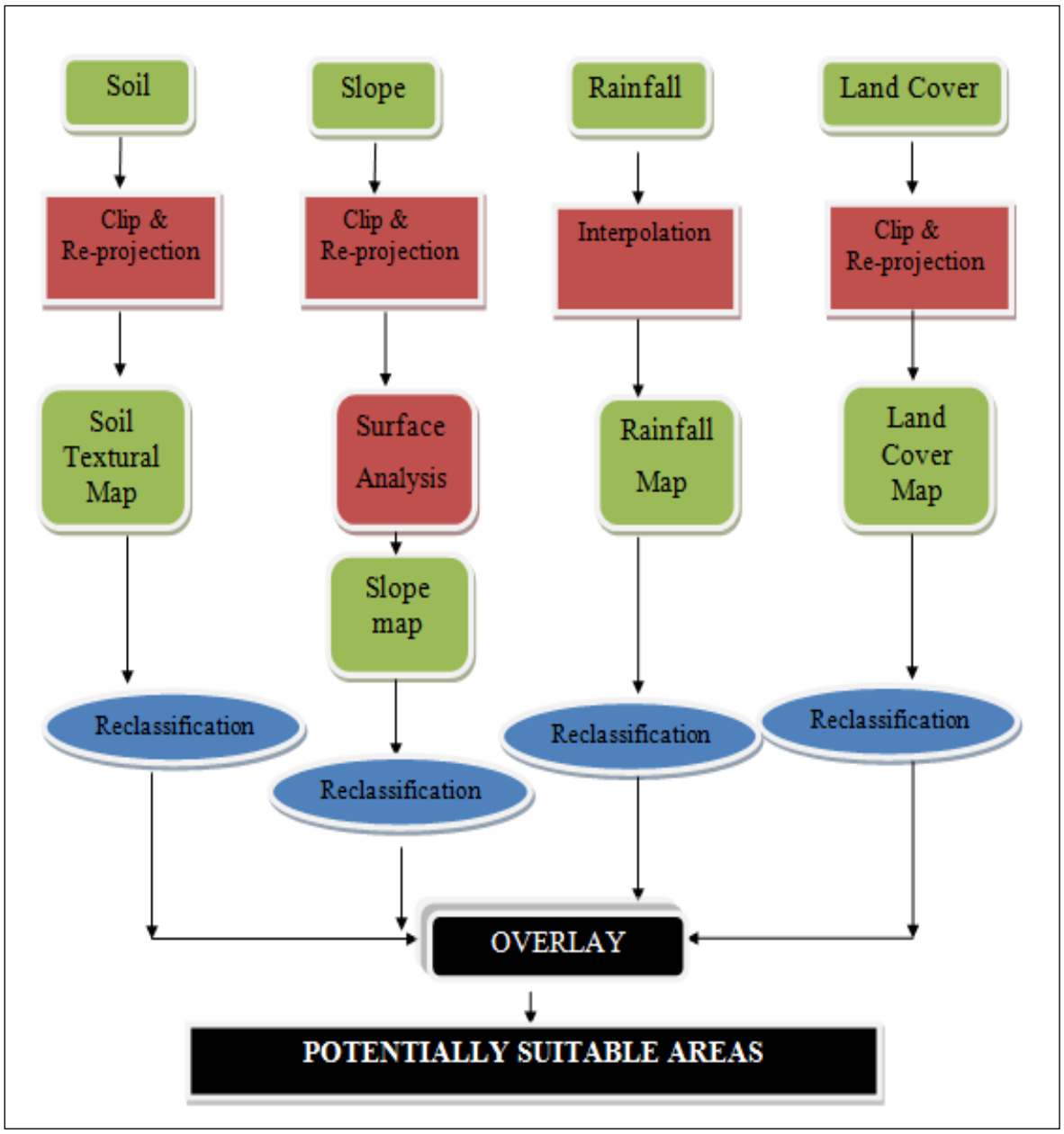

Figure 13: Flow chart for identification of potential sites.

4. RESULTS AND DISCUSSION

4.1 Identification of Potential RWH Areas

It was revealed that, major reason for the failure of rainwater harvesting projects and the slow adoption of rainwater harvesting techniques is the poor selection of suitable sites and matching of the practice with its technical and socio-economic requirements. A major knowledge gap would also exists concerning the identification of those areas in which the chances for the positive effects and adoption of rainwater harvesting techniques are high and to which further studies could be targeted.

A number of tools of ArcGIS were incorporated in this RWH mapping to solve various spatial problems, *i.e.* calculating each criterion (slope, rainfall, soil texture and land use/cover), reclassifying these values, clipping them, re-sampling it, re-projecting and over-laying to generate the final suitability map. All source maps were in vector type formats, each containing their related attribute files. These were converted into raster datasets and then re-sampled to the same cell size to enable the ArcGIS overlay operation.

4.2 RWH Criteria Database

The GIS dataset for each criterion required for the identification of suitable areas for pond RWH were obtained from EMA available data sets and enriched with data collected from Regional/Federal Agricultural Bureau, Water Bureau, National Meteorology Station and ground observation.

4.2.1 Soil textural map

The soil textural map of Harshin District was derived from the land suitability dataset of SR in combination with data obtained from soil sampled result of the study area. The soil texture layer was clipped to the study area and reclassified into five numerical categories and assigned suitability rankings for ponds RWH.

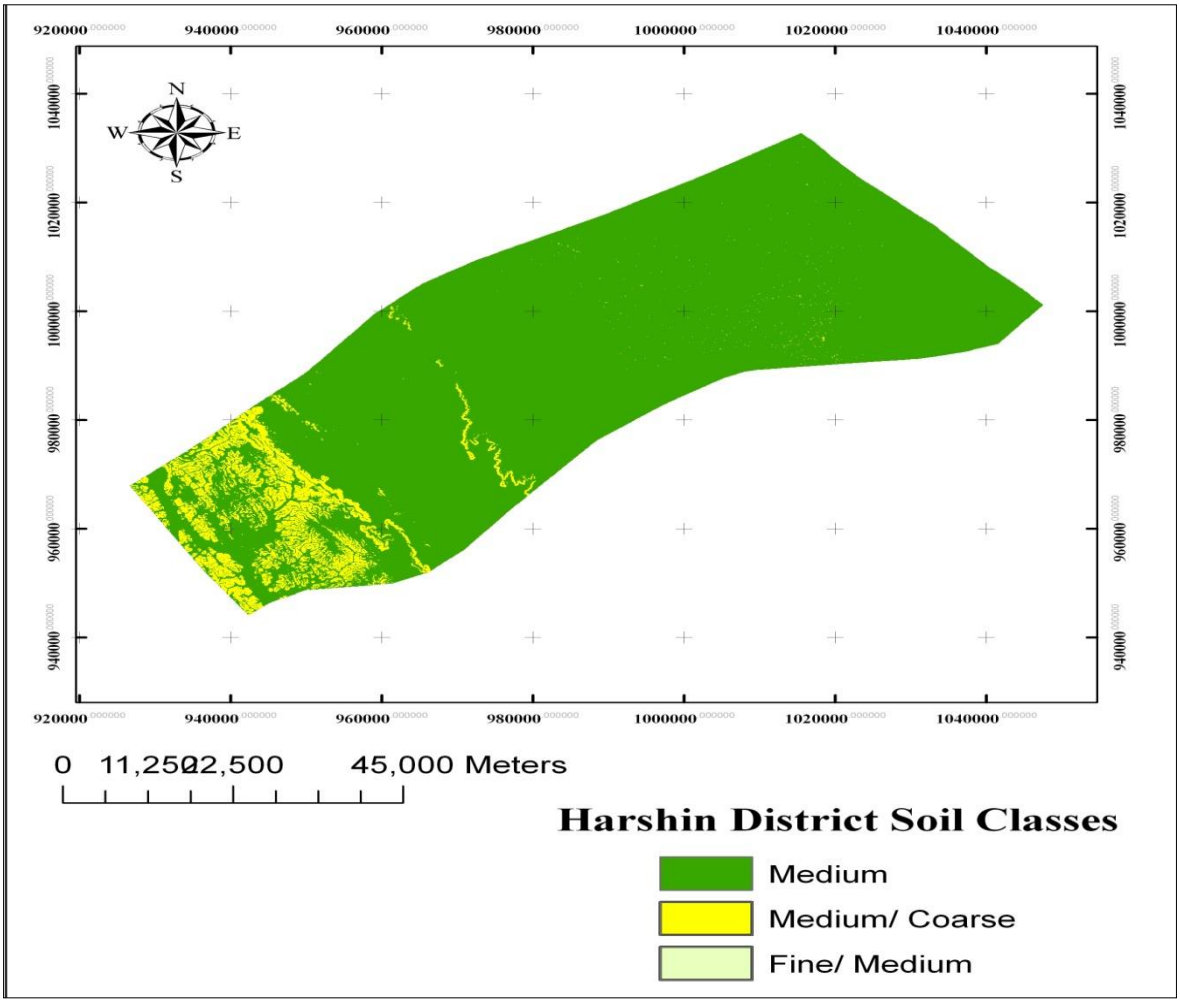

Figure 14: Harshin District soil map

From the final Harshin District's soil data table, it can be observed that soil type of the area predominantly falls under class medium soil textural class (Sandy loam) as presented in percentage below.

Table 9: Harshin soil data

Sr. No	Soil Textureal Classes	Area Coverage (ha)	Percentage
1	Medium	408,708.46	94.85
2	Medium and coarse	22,148.25	5.14
3	Fine/ Medium	43.09	0.01

4.2.2 Rainfall map

The rainfall map was generated by interpolating six rainfall stations values. The values were calculated by setting 67% probability of exceedance using data of six meteorological stations located in SR. The calculation was done for each year and for each station and the accumulated 67% probability of exceedance was calculated by using the annual rainfall data after rectifying. To get a surface rainfall map, the calculated values were interpolated using the Inverse Distance Weight (IDW) interpolation method of ArcGIS. The new data were clipped to the study area and re-sampled to 30 m cell size comprising only two class ranges.

Table 13: Harshin rainfall data

Sr. No	Annual Rainfall	Area Coverage (ha)	Percentage
1	200-400 mm	370,798.45	86.05
2	400-600 mm	60,101.35	13.95

Harshin District's annual rainfall ranges from 200 up to 600 mm dominantly ranging from 200mm to 400mm covering 86.05%.

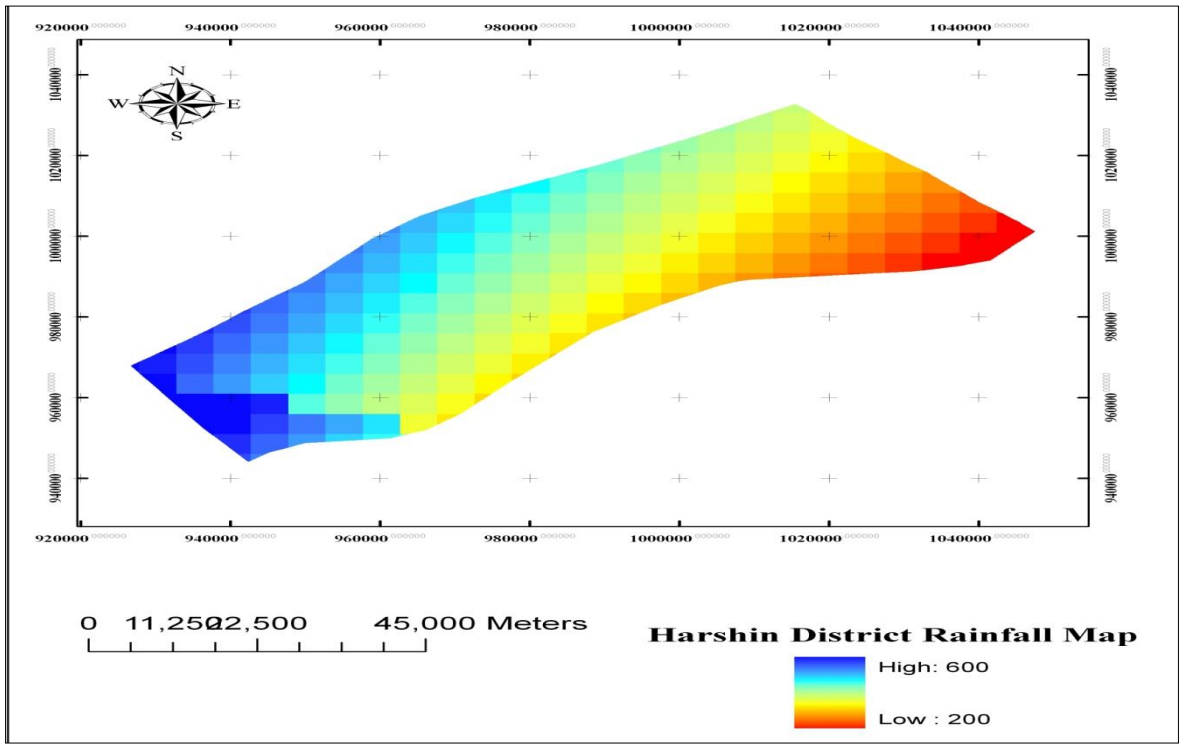

Figure 15: Harshin District rainfall map

4.2.3 Topography/ Slope map

The slope map of Harshin District that was expressed in percentage was derived from the DEM (elevation dataset) with 90 m resolution Clipped from SR. The slope map was reclassified into five classes based on the IMSD classification.

Table 11: Harshin Slope data

Sr. No	Topography	Area Coverage (ha)	Percentage
1	Mountainous	9,661.49	2.24
2	Hilly	20,226.32	4.69
3	Rolling	25,083.89	5.82
4	Undulating	163,811.97	38.02
5	Flat	212,116.13	49.23

Harshin District's topography ranges between undulating (2-8%) and flat terrain (0 - 2%) both cumulatively accounting for 87.25%.

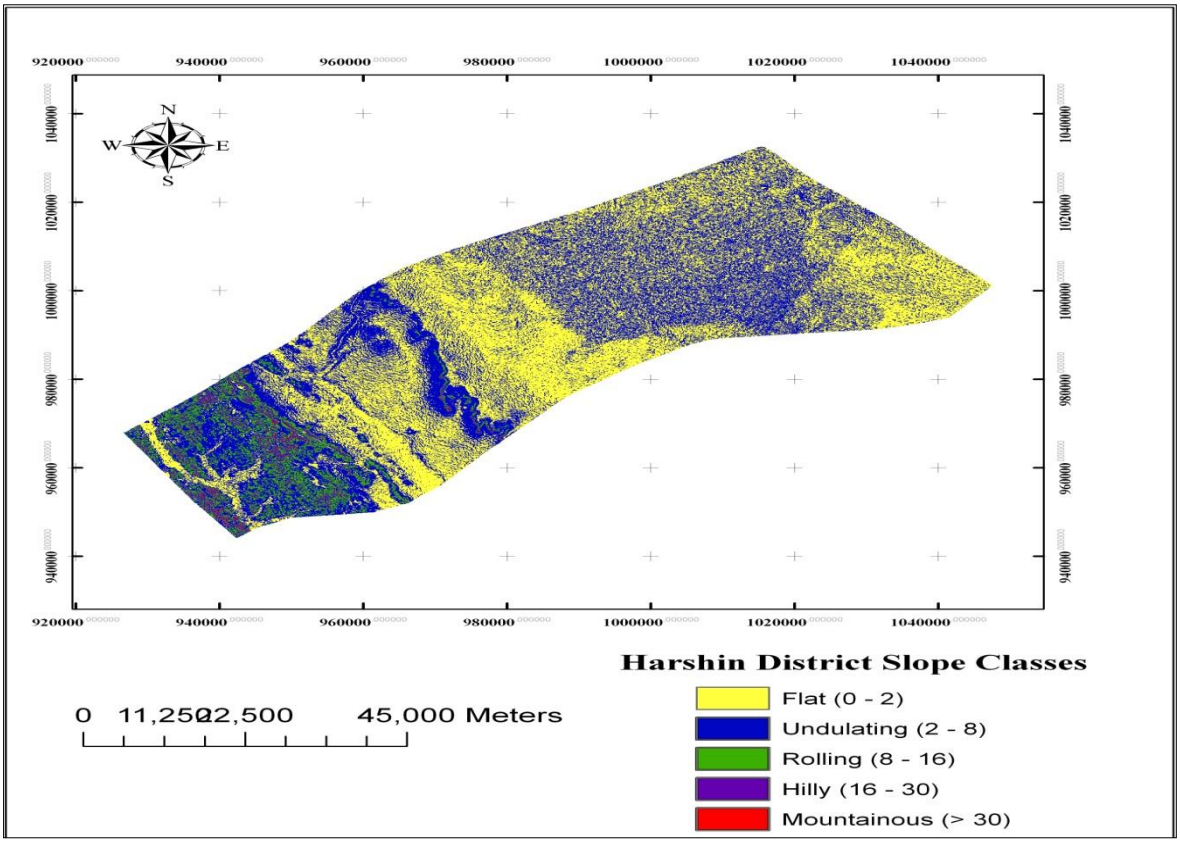

Figure 16: Harshin District slope map

4.2.4 Land use/cover map

The land cover map of Harshin District was clipped from land use/cover dataset of SR and from the aerial photo as well as the existing land use map of the region that was cross-checked using GPS & ground observation. The land cover map was reclassified into 5 classes by combining the above inputs.

Table 12: Harshin Land Cover Data

Sr. No	Land use/cover	Area Coverage (ha)	Percentage
1	Dense Shrub land	90,552.33	21.01
2	Exposed sand soil surface with scattered shrub & grass vegetation	2,152.17	0.50
3	Open grassland, open shrub land & bushed shrub grassland	338,195.30	78.49

Harshin District's land use/cover falls under a category Open grass/ shrub land/ bushed shrub grassland accounting for 78.49% of the total land.

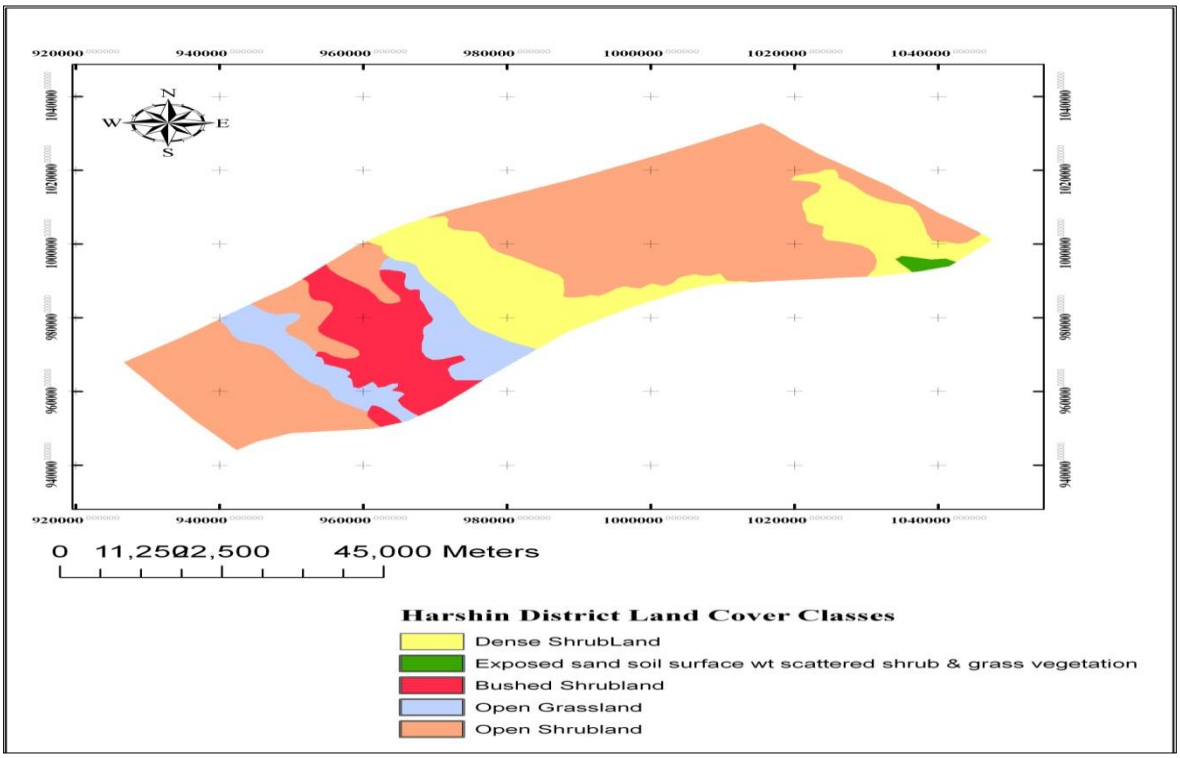

Figure 17: Harshin District land use/cover map

4.3 Identification of Areas Suitable for Pond RWH in Harshin District

The process of identifying suitable pond RWH was implemented in the ArcGIS model environment using the model builder of ArcGIS 9.1. The suitability model generated suitability map for pond RWH in Harshin District by integrating different input criteria maps using MCE by weighted overlay process. Different spatial analysis tools were incorporated in the model to solve various spatial problems in the process of identifying suitable areas.

At the time of soil sampling near constructed ponds indicated that most of the constructed ponds have considerable seepage problems. Furthermore, most observed ponds could not be filled within two or three showers confirming that except for the erratic rainfall, the catchment envisages no problem. Therefore, it was concluded that, soil texture being responsible for seepage, was given more importance followed by rainfall than the other criteria which in turn resulted in a higher weight for soil texture accordingly.

Finally, the suitability model generated suitability map for Harshin District pond RWH each with five suitability classes, i.e. Very Highly suitable, Highly Suitable, Moderately suitable, Less Suitable and Non suitable (Figure 18).

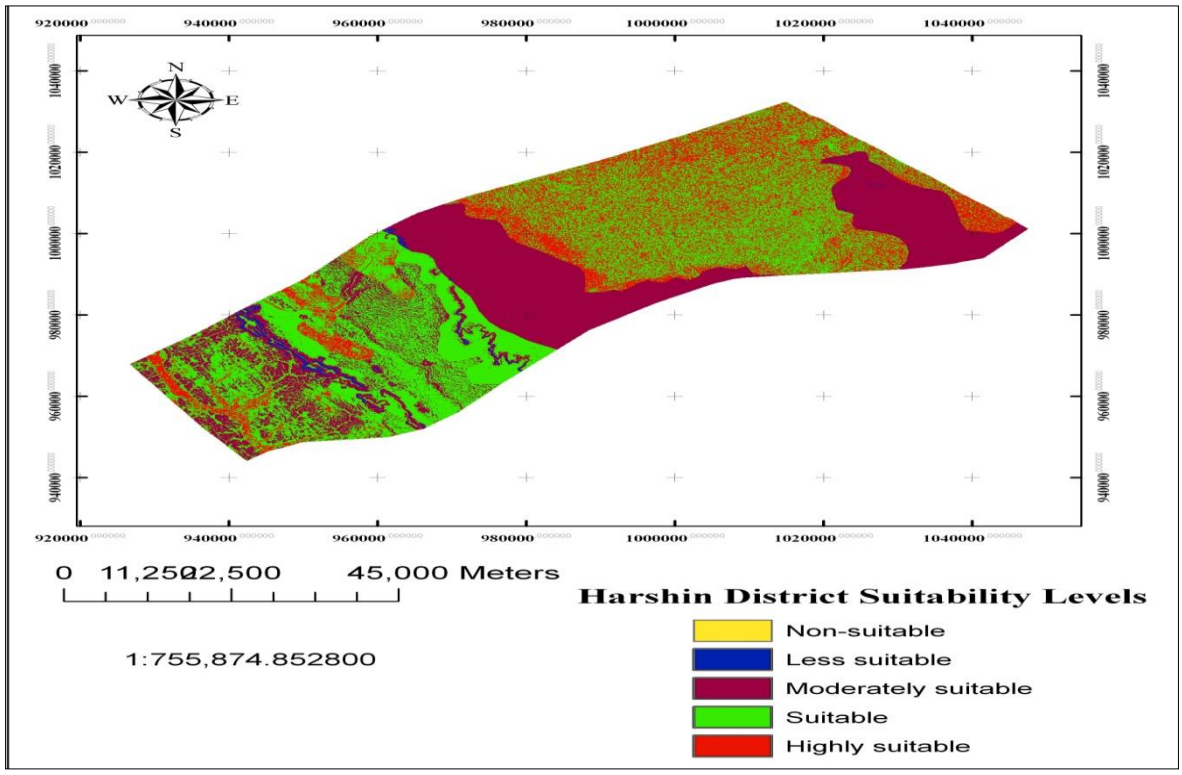

Figure 18: Harshin District Pond Suitability Map

The spatial distribution of the suitability map showed that the central and eastern part of the study areas were dominated by Moderate (dark-red), high (green) and very high (red) suitability category. On the other hand, the western part of the study area showed a very small portion categorized as less (blue) suitability class.

The spatial distribution of the suitability map showed that about 45.69% of the Harshin land falls under highly to very highly suitable category which covers around 1,968.90 Km^2 of land. The moderately suitable class is about 54.29% of the Harshin land which covers about 2,239.49 Km^2 areas. The less and non-suitable land of this district for pond RWH is 0.01% which accounts for 0.61Km^2 of land.

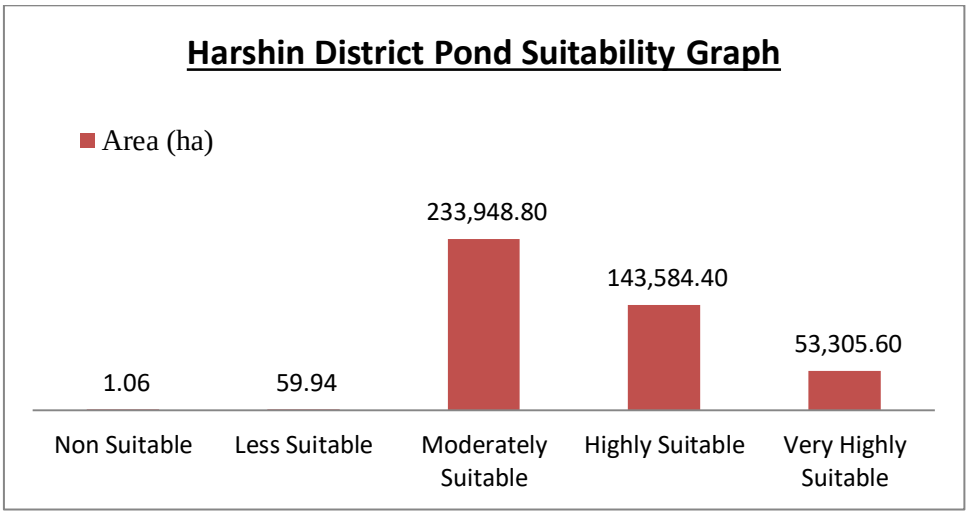

Figure 19: Harshin District Pond Suitability Graph

The majority of the areas with very high to high suitability have slopes between 2 and 8% and with an open grass land cover. The major soil type in the very high and high suitable area is sandy loam (medium texture) and the rainfall ranges from 200 up to 400 mm.

4.4 Validation of the Suitability Levels

In order to check for applicability of the suitability ranks that were developed, the locations of the existing RWH technologies were compared with locations obtained after running the Multi-Criteria Analysis (MCE) tool in Arc Map 9.1. For the purpose of the validation, the observed pond RWH structures were first rated in two categories: successful, the ones

filled with water at the time of observation and unsuccessful, those structures were proved as having various problems/empty categorized as unsuccessful category as shown under.

Figure 20: Successful Pond RWH Structure

Figure 21: Unsuccessful Pond RWH Structure

The assumption that was made for this validation was if the pond RWH structures which were categorized as successful category were found in moderately suitable to very highly suitable areas in the derived suitability map, the result from the suitability model would be proofed as valid.

The results shown in table 13 and figure 22 indicated that 33.3 % of pond RWH technologies were located in the areas of high suitability, 43.3 % located in the areas of moderate suitability whilst 10 % were located in low suitable areas.

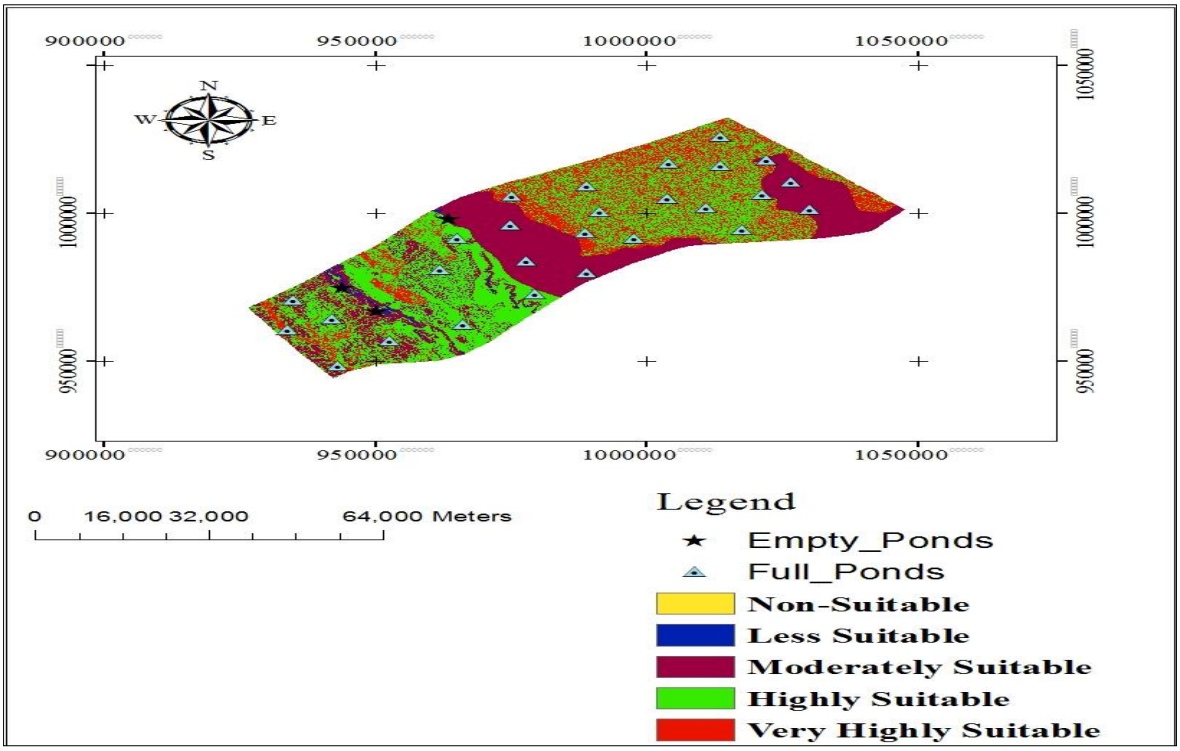

Figure 22: Location of existing RWH technologies under established suitability rank

Thus it can be concluded that the established suitability ranks agreed with the experience and local knowledge of the pastoralists. The validation results showed that the database and methodology used for developing the suitability map including the suitability levels of the criteria and the criteria's relative importance weights have shown valid results. This method of validating a model for identifying suitable RHW areas has been used by other researchers elsewhere (Girma, 2009; Mbilinyi et al., 2014; Nyirenda, 2016).

Table 13: Comparisons of RWH technologies actual locations and suitability levels

Sr. No	Level of Suitability	Observation	Percentage
1	Very Highly Suitable	4	13.33
2	Highly Suitable	10	33.33
3	Moderately Suitable	13	43.33
4	Less Suitable	3	10.0
5	Non Suitable	-	-
Total		**30**	**100**

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Utilizing runoff in an efficient and sustainable manner is crucial to improve the performance of Pastoralists in the Harshin District. Mostly, due to the hasty implementation of many RWH interventions, often driven by the need to satisfy Woreda specific RWH quota, the guidelines of RWH manuals are not followed. The results are an improper site selection locating ponds in areas with less suitable soils, improper design (only one type of tanks and ponds are constructed everywhere), lack of farmer involvement during the planning and implementation, lack of materials like plastic sheet to reduce seepage in ponds and lack of maintenance.

Providing information on the suitability of areas for different types of RWH interventions is an important step prior to the actual planning and implementation. Identifying potential areas for RHW requires spatial knowledge on a number of critical Bio-physical factors such as soil, climate, topography and land use.

In this study, the integration of factors for locating suitable areas of RWH technologies was done in a GIS based platform in order to generate suitability maps by using the Arc GIS 9.1 model builder. This model used a multi-criteria evaluation that combines different factors such rainfall, soil texture, slope and land use/cover through a weighted overlaying process. The model generated a suitability map for pond RWH technologies. The results from the model indicated that the majority of the land was moderately suitable (54.29%) and highly suitable (33.32%). These results were also validated using information that was obtained from the field observation which showed that 33.33% RWH technologies were located in the areas of high suitability and with 43.33% located in the areas of moderate suitability whilst 10% were located in low suitable areas. These results show the reliability of the developed RWH model because most of the sites are appropriately located. Therefore the accuracy of the model is found to be satisfactory.

5.2 Recommendations

GIS-based information is helpful for decision-makers and planners, but one should be careful in the interpretation of the generated information. There is need for the regional government through the District Agricultural office to help in creating awareness of the existing potential and investing in the implementation of RWH technologies in more suitable areas.

The suitability model used a MCE process that combined different biophysical factors: soil texture, rainfall, slope and land use/cover. The generated map also showed that, the dominant soil type in Harshin District of Somali Region being Sandy Loam, due care should be given in seepage loss control through either cement lining or use of geo-membrane. On the other hand, socioeconomic factors (e.g. market access, infrastructure, population density/ living status, close proximity to homesteads) which are also necessary for a better complete assessment of the suitability of land for RWH, were not considered due to lack of readily available data for this large area. It is therefore recommended to include such socio-economic factors in future studies to improve the suitability assessment.

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7. APPENDICES

Appendix Table 1. Harshin Soil Sampling Spots

Sr. no	Sample Code	GPS UTM Wgs84 Readings		Soil textural class
		X-Coordinates	Y-Coordinates	
1	S_1	1013639.934	1016000.318	Sandy loam
2	S_2	1013466.243	1026248.051	Sandy loam
3	S_3	1004086.962	1016695.080	Sandy loam
4	S_4	1003739.581	1004884.133	Sandy loam
5	S_5	1011034.578	1002105.087	Sandy loam
6	S_6	997660.417	991509.973	Sandy loam
7	S_7	991233.873	1000889.254	Sandy loam
8	S_8	988975.898	1009400.083	Loamy Sand
9	S_9	1021456.001	1006621.037	Sandy loam
10	S_{10}	965006.624	991857.354	Sandy loam
11	S_{11}	979596.617	972751.411	Sandy loam
12	S_{12}	952674.606	956945.585	Sandy loam
13	S_{13}	950416.631	966845.937	Loamy Sand
14	S_{14}	943816.396	974835.695	Sandy loam
15	S_{15}	963096.030	998110.208	Loamy Sand
16	S_{16}	975080.667	996373.304	Sandy loam
17	S_{17}	977859.713	984041.286	Sandy loam
18	S_{18}	988975.898	980220.097	Sandy loam
19	S_{19}	989149.588	993941.638	Sandy loam
20	S_{20}	1022150.763	1018084.603	Sandy loam
21	S_{21}	1026666.713	1010442.225	Sandy loam
22	S_{22}	1029966.830	1001584.016	Sandy loam
23	S_{23}	1017634.813	994636.400	Sandy loam
24	S_{24}	934263.425	960419.393	Loamy Sand
25	S_{25}	935131.877	970667.126	Sandy loam
26	S_{26}	941905.802	964414.272	Sandy loam
27	S_{27}	943121.635	948087.375	Sandy loam
28	S_{28}	966048.766	962503.677	Sandy loam
29	S_{29}	961880.197	980914.859	Loamy Sand
30	S_{30}	1021282.311	1006273.656	Sandy loam

Appendix Table 2. Rainfall data of SR for six Woredas

No	Data Years (G.C)	Annual Rainfall Total (mm)					
		Jig-Jiga	Kebri Dehar	Gode	Bisidimo	Fedis	Degahabur
1	1976	1,084.80	555.6	64.8	736.8	1,414.80	386.4
2	1977	699.6	1,078.80	424.8	661.2	1,074.00	838.8
3	1978	649.2	601.2	111.6	514.8	1,339.20	499.2
4	1979	678	548.4	58.8	496.8	781.2	513.6
5	1980	520.8	346.8	44.4	448.8	268.8	176.4
6	1981	601.2	398.4	205.2	735.6	628.8	418.8
7	1982	680.4	337.2	195.6	1,036.80	294	578.4
8	1983	535.2	255.6	285.6	1,022.40	286.8	488.4
9	1984	400.8	355.2	70.8	351.6	138	190.8
10	1985	516	286.8	270	447.6	352.68	472.8
11	1986	625.2	229.2	196.8	627.6	268.8	766.8
12	1987	667.2	206.4	295.2	1,104.00	1,269.60	492
13	1988	534	163.2	258	692.4	794.4	376.8
14	1989	843.6	324	322.8	824.4	1,028.40	412.8
15	1990	792	292.8	115.2	564	553.2	178.8
16	1991	672	235.2	150	579.6	484.8	279.6
17	1992	562.8	134.4	380.4	685.2	663.6	252
18	1993	784.8	327.6	55.2	597.6	598.8	334.8
19	1994	579.6	406.8	297.6	735.6	715.2	324
20	1995	512.4	217.2	202.8	667.2	844.8	342
21	1996	646.8	482.4	122.4	921.6	1,030.80	162
22	1997	613.2	388.8	535.2	879.6	817.2	522
23	1998	489.6	190.8	259.2	465.6	763.2	265.2
24	1999	964.8	174	196.8	723.6	792	240
25	2000	495.6	291.6	303.6	561.6	847.2	476.4
26	2001	553.2	184.8	135.6	468	542.4	361.2
27	2002	645.6	228	225.6	600	751.2	400.8
28	2003	560.4	224.4	243.6	607.2	634.8	171.6
29	2004	565.2	390	240	676.8	608.4	303.6
30	2005	844.8	307.2	199.2	571.2	572.4	336
31	2006	835.2	232.8	360	640.8	933.6	556.8
32	2007	519.6	270	145.2	495.6	714	250.8
33	2008	490.8	261.6	232.8	555.6	726	357.6
34	2009	643.2	356.4	153.6	333.6	858	193.2
35	2010	628.8	391.2	142.8	402	716.4	424.8

Appendix Table 3. Ranking and Probability of occurrence of Rainfall data for D.bour and Fedis stations.

Degahbour				Fedis			
Year	Ranked RF Total (mm)	m	P (%)	Year	Ranked RF Total (mm)	m	P (%)
1977	838.8	1	1.8	1976	1,414.80	1	1.8
1986	766.8	2	4.6	1978	1,339.20	2	4.6
1982	578.4	3	7.4	1987	1,269.60	3	7.4
2006	556.8	4	10.3	1977	1,074.00	4	10.3
1997	522	5	13.1	1996	1,030.80	5	13.1
1979	513.6	6	16	1989	1,028.40	6	16
1978	499.2	7	18.8	2006	933.6	7	18.8
1987	492	8	21.6	2009	858	8	21.6
1983	488.4	9	24.5	2000	847.2	9	24.5
2000	476.4	10	27.3	1995	844.8	10	27.3
1985	472.8	11	30.1	1997	817.2	11	30.1
2010	424.8	12	33	1988	794.4	12	33
1981	418.8	13	35.8	1999	792	13	35.8
1989	412.8	14	38.7	1979	781.2	14	38.7
2002	400.8	15	41.5	1998	763.2	15	41.5
1976	386.4	16	44.3	2002	751.2	16	44.3
1988	376.8	17	47.2	2008	726	17	47.2
2001	361.2	18	50	2010	716.4	18	50
2008	357.6	19	52.8	1994	715.2	19	52.8
1995	342	20	55.7	2007	714	20	55.7
2005	336	21	58.5	1992	663.6	21	58.5
1993	334.8	22	61.3	2003	634.8	22	61.3
1994	324	23	64.2	1981	628.8	23	64.2
2004	303.6	24	67	2004	608.4	24	67
1991	279.6	25	69.9	1993	598.8	25	69.9
1998	265.2	26	72.7	2005	572.4	26	72.7
1992	252	27	75.5	1990	553.2	27	75.5
2007	250.8	28	78.4	2001	542.4	28	78.4
1999	240	29	81.2	1991	484.8	29	81.2
2009	193.2	30	84	1985	352.68	30	84
1984	190.8	31	86.9	1982	294	31	86.9
1990	178.8	32	89.7	1983	286.8	32	89.7
1980	176.4	33	92.6	1980	268.8	33	92.6
2003	171.6	34	95.4	1986	268.8	34	95.4
1996	162	35	98.2	1984	138	35	98.2

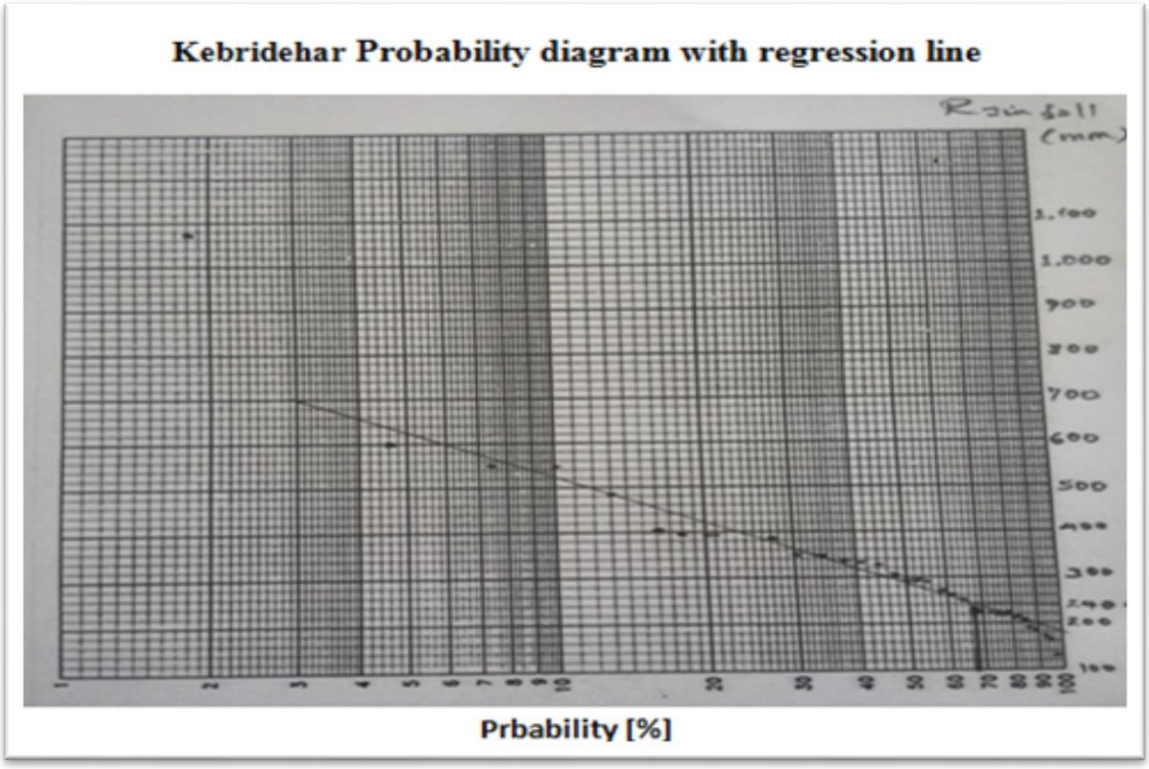
Appendix Table 4. Ranking and Probability of occurrence of Rainfall data for Bisidimo and Gode stations.

Bisidimo				Gode			
Year	Ranked RF Total (mm)	m	P (%)	Year	Ranked RF Total (mm)	m	P (%)
1987	1,104.00	1	1.8	1997	535.2	1	1.8
1982	1,036.80	2	4.6	1977	424.8	2	4.6
1983	1,022.40	3	7.4	1992	380.4	3	7.4
1996	921.6	4	10.3	2006	360	4	10.3
1997	879.6	5	13.1	1989	322.8	5	13.1
1989	824.4	6	16	2000	303.6	6	16
1976	736.8	7	18.8	1994	297.6	7	18.8
1981	735.6	8	21.6	1987	295.2	8	21.6
1994	735.6	9	24.5	1983	285.6	9	24.5
1999	723.6	10	27.3	1985	270	10	27.3
1988	692.4	11	30.1	1998	259.2	11	30.1
1992	685.2	12	33	1988	258	12	33
2004	676.8	13	35.8	2003	243.6	13	35.8
1995	667.2	14	38.7	2004	240	14	38.7
1977	661.2	15	41.5	2008	232.8	15	41.5
2006	640.8	16	44.3	2002	225.6	16	44.3
1986	627.6	17	47.2	1981	205.2	17	47.2
2003	607.2	18	50	1995	202.8	18	50
2002	600	19	52.8	2005	199.2	19	52.8
1993	597.6	20	55.7	1986	196.8	20	55.7
1991	579.6	21	58.5	1999	196.8	21	58.5
2005	571.2	22	61.3	1982	195.6	22	61.3
1990	564	23	64.2	2009	153.6	23	64.2
2000	561.6	24	67	1991	150	24	67
2008	555.6	25	69.9	2007	145.2	25	69.9
1978	514.8	26	72.7	2010	142.8	26	72.7
1979	496.8	27	75.5	2001	135.6	27	75.5
2007	495.6	28	78.4	1996	122.4	28	78.4
2001	468	29	81.2	1990	115.2	29	81.2
1998	465.6	30	84	1978	111.6	30	84
1980	448.8	31	86.9	1984	70.8	31	86.9
1985	447.6	32	89.7	1976	64.8	32	89.7
2010	402	33	92.6	1979	58.8	33	92.6
1984	351.6	34	95.4	1993	55.2	34	95.4
2009	333.6	35	98.2	1980	44.4	35	98.2

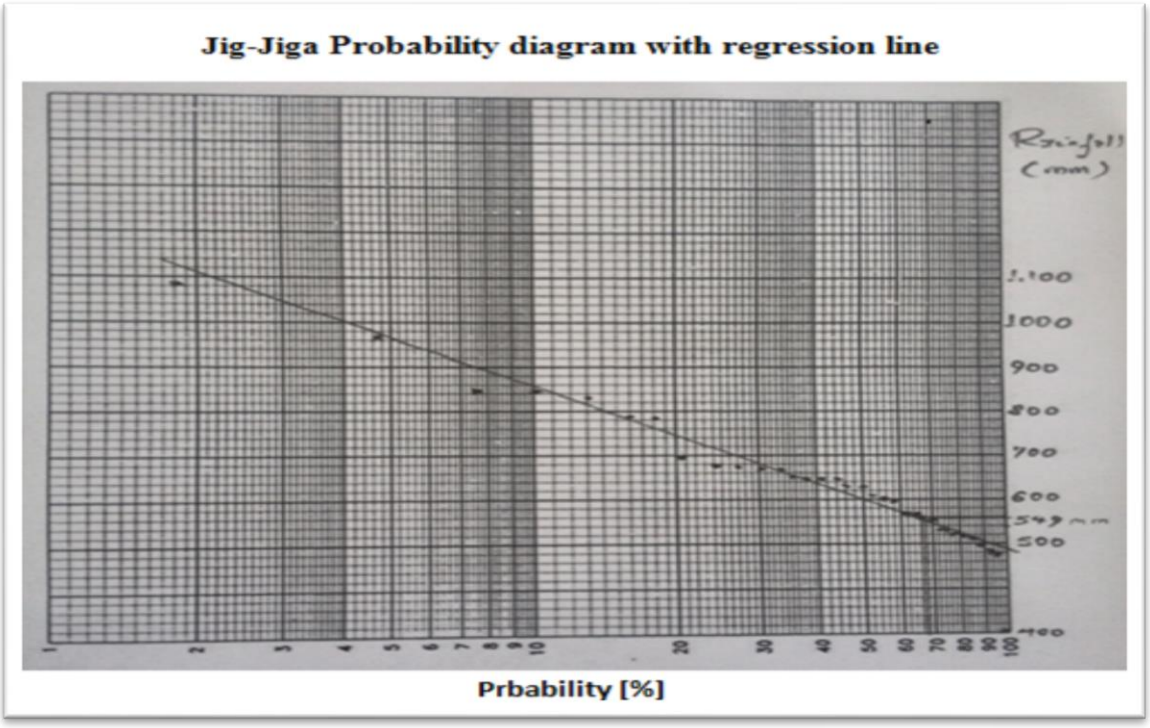
Appendix Table 5. Ranking and Probability of occurrence of Rainfall data for Jigjiga and Kebridehar stations.

Jig-jiga				Kebridehar			
Year	Ranked RF Total (mm)	m	P (%)	Year	Ranked RF Total (mm)	m	P (%)
1976	1,084.80	1	1.8	1977	1,078.80	1	1.8
1999	964.8	2	4.6	1978	601.2	2	4.6
2005	844.8	3	7.4	1976	555.6	3	7.4
1989	843.6	4	10.3	1979	548.4	4	10.3
2006	835.2	5	13.1	1996	482.4	5	13.1
1990	792	6	16	1994	406.8	6	16
1993	784.8	7	18.8	1981	398.4	7	18.8
1977	699.6	8	21.6	2010	391.2	8	21.6
1982	680.4	9	24.5	2004	390	9	24.5
1979	678	10	27.3	1997	388.8	10	27.3
1991	672	11	30.1	2009	356.4	11	30.1
1987	667.2	12	33	1984	355.2	12	33
1978	649.2	13	35.8	1980	346.8	13	35.8
1996	646.8	14	38.7	1982	337.2	14	38.7
2002	645.6	15	41.5	1993	327.6	15	41.5
2009	643.2	16	44.3	1989	324	16	44.3
2010	628.8	17	47.2	2005	307.2	17	47.2
1986	625.2	18	50	1990	292.8	18	50
1997	613.2	19	52.8	2000	291.6	19	52.8
1981	601.2	20	55.7	1985	286.8	20	55.7
1994	579.6	21	58.5	2007	270	21	58.5
2004	565.2	22	61.3	2008	261.6	22	61.3
1992	562.8	23	64.2	1983	255.6	23	64.2
2003	560.4	24	67	1991	235.2	24	67
2001	553.2	25	69.9	2006	232.8	25	69.9
1983	535.2	26	72.7	1986	229.2	26	72.7
1988	534	27	75.5	2002	228	27	75.5
1980	520.8	28	78.4	2003	224.4	28	78.4
2007	519.6	29	81.2	1995	217.2	29	81.2
1985	516	30	84	1987	206.4	30	84
1995	512.4	31	86.9	1998	190.8	31	86.9
2000	495.6	32	89.7	2001	184.8	32	89.7
2008	490.8	33	92.6	1999	174	33	92.6
1998	489.6	34	95.4	1988	163.2	34	95.4
1984	400.8	35	98.2	1992	134.4	35	98.2

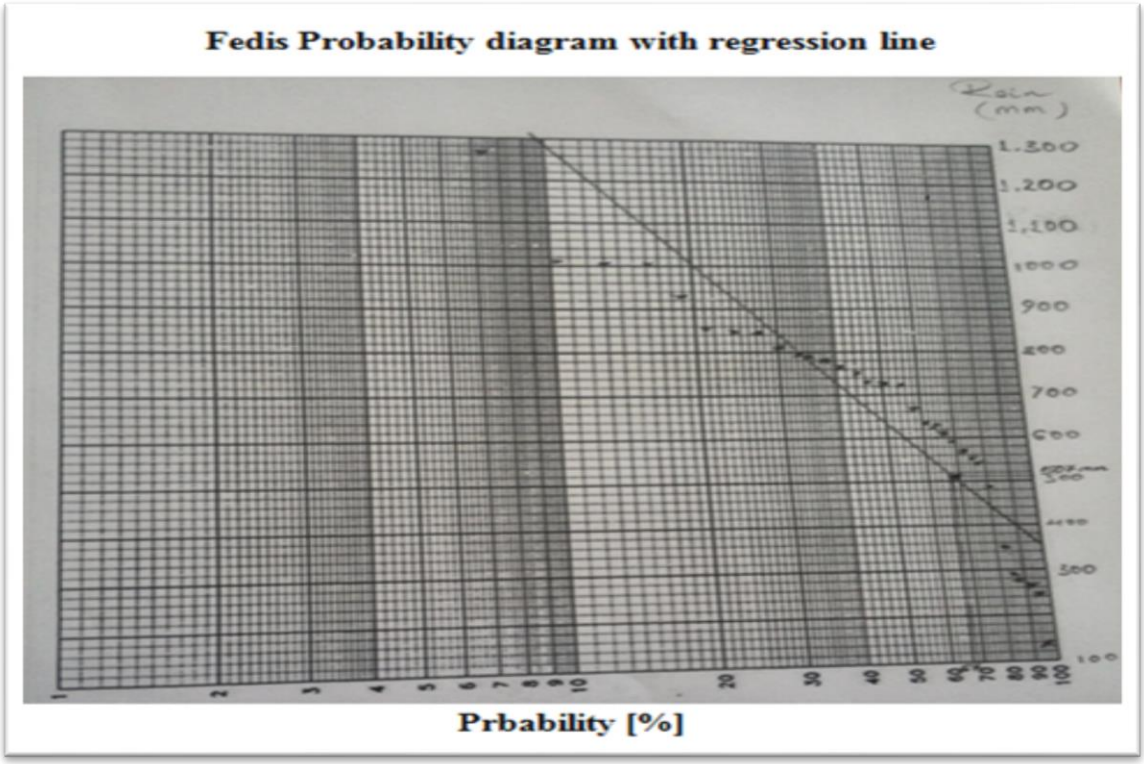
Appendix Figure 1. Kebridehar Probability Diagram with Regression Line



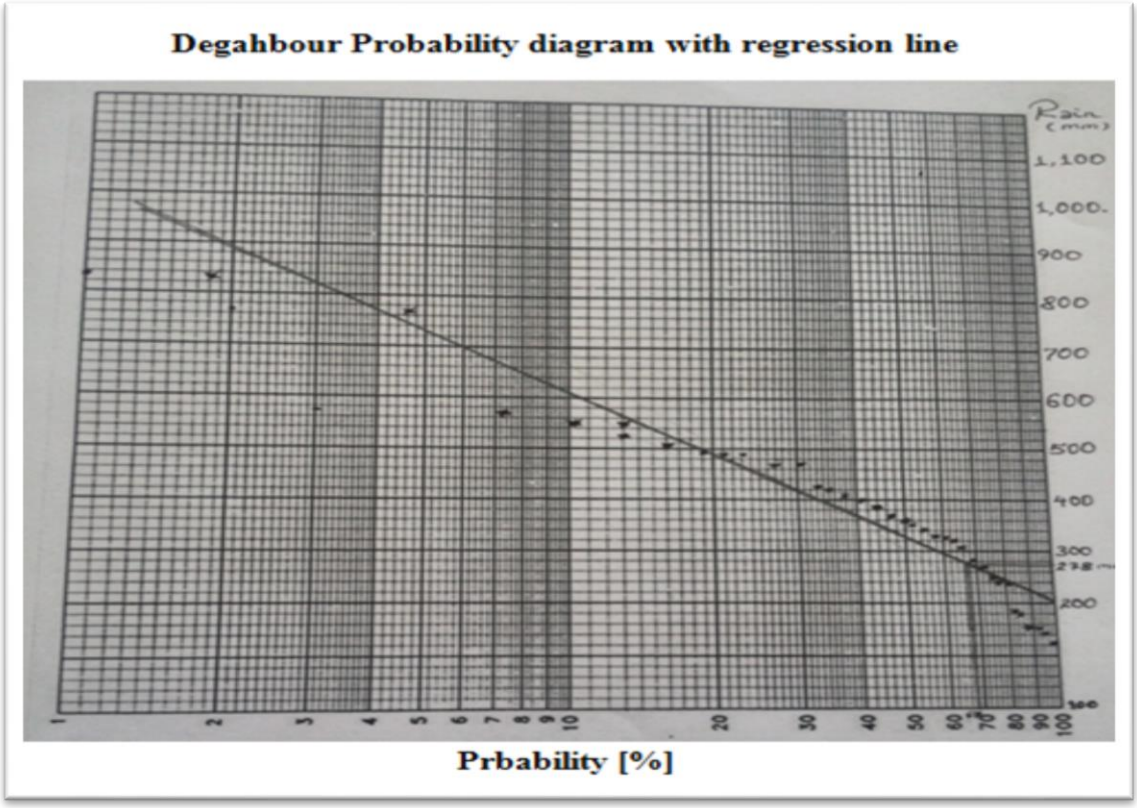
Appendix Figure 2. Jig-Jiga Probability Diagram with Regression Line



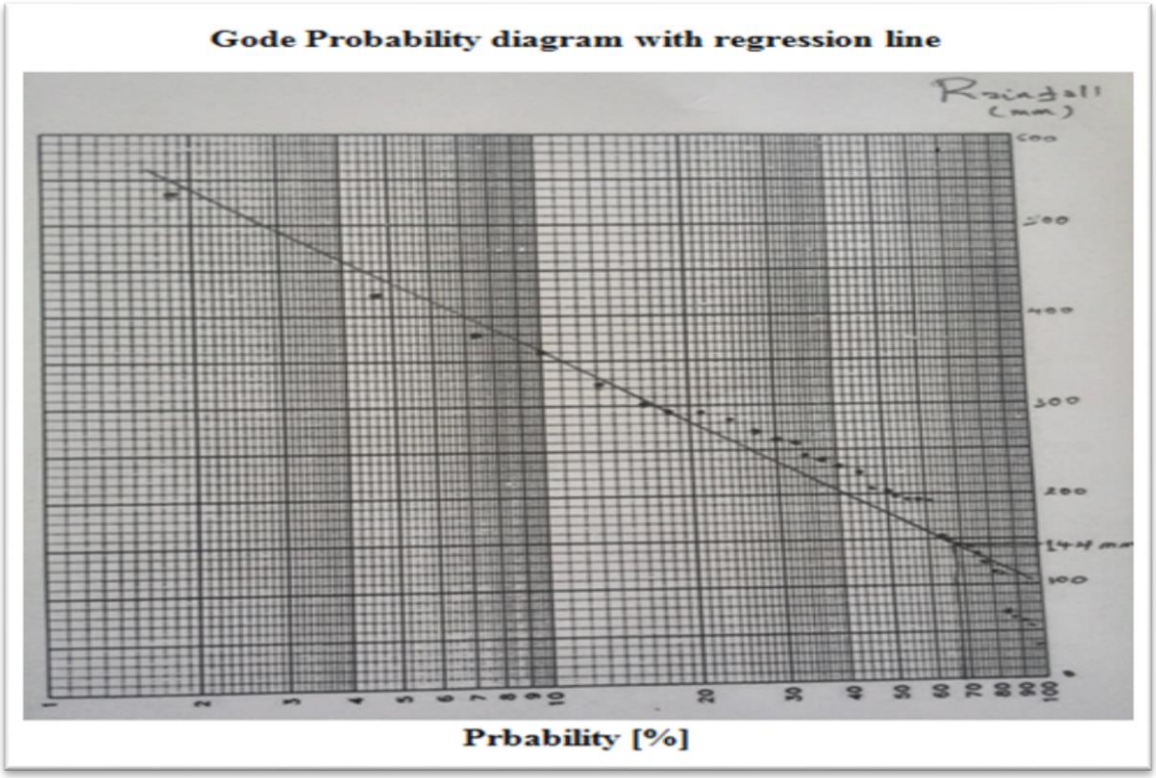
Appendix Figure 3. Fedis Probability Diagram with Regression Line



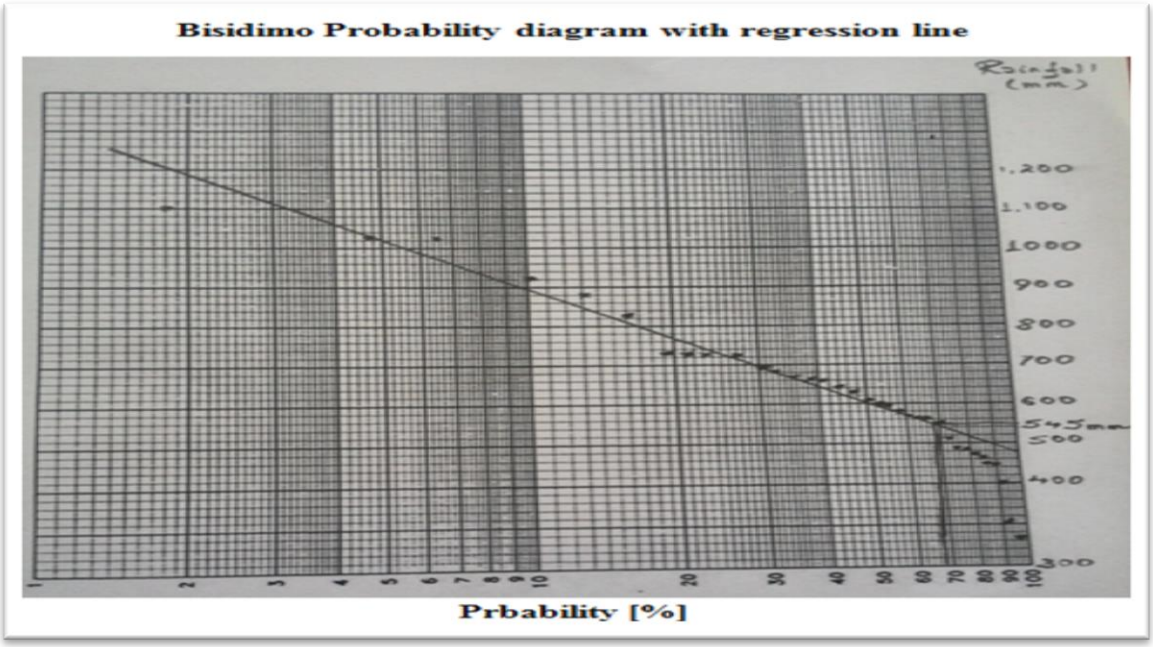
Appendix Figure 4. Degahbour Probability Diagram with Regression Line



Appendix Figure 5. Gode Probability Diagram with Regression Line



Appendix Figure 6. Bisidimo Probability Diagram with Regression Line



Appendix Picture: Harshin area RWH structures.