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Potential Bright Spots for Flood-based Irrigation Systems in Marsabit County, Northern Kenya

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CONTENTS

List of Figures

List of Tables

1. INTRODUCTION

1.1 General

Kenya's agriculture is dominated by small agricultural production systems where 75 % of the national food production is primarily produced for subsistence of the farming households (P. Alila and R. Atieno, 2006). Rapid population growth, effects of climate change as well as shortage of land and water lead to the depletion of natural resources. The challenge is prominent in arid and semi-arid parts of the country like Turkana and Marsabit counties, where the rainfall is much smaller than the annual potential evapotranspiration.

The arid and semi-arid areas of the country make up to 80 % of the country's territory and approximately 30 % of the Kenyan population lives in this region. Some of the greatest challenge in this area is the high frequency of drought periods threatening food security, poverty eradication and peaceful co-existence. The famine of 2011 was one of the worst recent human catastrophes and had a significant impact on the livelihoods of the region and its inhabitants. Therefore, this study focuses on addressing the challenges which are associated with shortage of moisture through utilization of floods occurring in the counties. The utilization of flood for agriculture hereafter is referred as flood based farming.

Flood based farming is a unique form of water resource management that uses often unpredictable and occasionally destructive water supply from ephemeral streams in climate smart agriculture for crop, rangeland and agro-forest production, domestic and livestock water supply, recharging groundwater through

- Mainly Spate irrigation – direct diversion of flashy foods in to the downstream command area
- Flood inundation and recession: rivers overflow their embankment and flood adjacent areas
- Flood spreading weirs- direct diversion/storage of flashy foods in to/at the upstream side command area
- Road water harvest – harvesting flood from road culverts to supplement nearby cultivated land.

Spate irrigation is one of the traditional practices employed by farmers/ agro-pastoralists to supplement rain fed agriculture. It can occur particularly where lowland areas are bordered by mountainous or high land catchments where short duration floods (from a few hours to a few days) flow from the catchments in ephemeral streams. These ephemeral streams are also sources of fertile sediments which are characterized by deep and fertile soil suitable for agriculture as a result of many years of alluvial deposition.

Flood-based farming systems accounts for over 30 and 15 million hectares across the world and Sub-Saharan Africa respectively. It also supports around 75 million most vulnerable segments of society across the world. Flood based farming practices is found in the Middle East, North Africa, West Asia, East Africa and parts of Latin America. In some countries it has a long history – more than 5000 years in Yemen, Pakistan and Iran (F. Vansteenbergen et.al 2010). The arid and semi-arid areas of Kenya make up to 80% of the country's territory and approximately 30% of the Kenyan population lives in this region. According to Overview paper spate irrigation # 8, the spate irrigation potential of Kenya could reach as much as 800,000 ha. The paper also discusses about some of the spate irrigation systems in Kenya including:

- The Pokomo and Marakote people along the Tana River
- The Somalis in North Eastern Province and newly introduced in Mandera District (Takaba and Banisa Divisions).
- Over flow from Daua River along the Kenya Ethiopia boarder is used in areas of Rhamu, RhamuDimtu, Malka-Mari, Harere.
- In Wajir District Buna Division - Korondile Location.
- In Habaswein District flood fed.
- The North Eastern Province includes Modogashe especially along Lagdera dry stream in Garissa District and Booni Forest area in Masalani District. Dasheik (ox-bow) farming is practiced along the lower reaches of the Tana River.
- Over flow from the Tana within the immediate flood plains that extends about 2 to 5 Km provide adequate moisture for crops grown after the flood event.
- The Marakwet in Northern Rift Valley in Kenya.

According to this paper, the mostly grown crops by the flood fed/spate irrigation are sorghum, maize and rarely rice.

The new agriculture sector program implemented by GIZ and with funding from the German Government aims at contributing to higher drought resilience in the two regions of Northern Kenya (Marsabit and Turkana counties), among others. The field interventions have focused on supporting the two counties to implement activities for sustainable intensification of small-scale production systems, drought resilient pastoral system and transfer of climate-sensitive technologies to enhance food security and household incomes. The purpose of this field research was; to explore the bright spots for using flood based farming in the Marsabit County. This report is therefore, prepared based on the invitation made by the Client and the Terms of Reference (TOR) prepared for this purpose. The required services are namely ***"the Identification of potential bright spots for flood-based irrigation systems in Turkana and Marsabit County, northern Kenya".***

1.2 Objective

As stipulated by the Client, the overall objective of the study is to introduce improved flood water utilization system to Marsabit County that can serve as a model for scaling up. It generally aims to demonstrate feasible and efficient way of using flood water through improved diversion, storage, canal and associated structures and application systems. Furthermore, the study has included identifying potential bright spots where properly designed and managed flood-based irrigation systems are having tangible positive impacts on the livelihoods of the respective rural communities in Marsabit County, northern Kenya.

The specific objectives of the assignment are:

Assess three or more pre-selected sites in Marsabit County with a high potential for spate and flood irrigation regarding their irrigation potential, structure type, as well as their rough costs, long-term maintenance and capacity needs, as well as imaginable risks of failures and how to address/reduce them.

1.3 Project Area Description

1.3.1 Location

Marsabit is Kenya's most arid and least inhabited County. It is located in Eastern Kenya bordering Ethiopia to the North and North East, Wajir County to the East, Isiolo County to the South East, Samburu County to the South and South West and Lake Turkana to the West and North West. The total area of the County is estimated around 66,923 Km². The County is divided into four sub-counties (Marsabit, North Horr Chalbi, Laisamis and Moyale). Marsabit town, on Marsabit Mountain, is the capital of the County, and the mountain is home to most of the district's agriculturalists, which include Burji, Boran, and Ariaal and Rendille communities (Fratkin et.al, 2004).

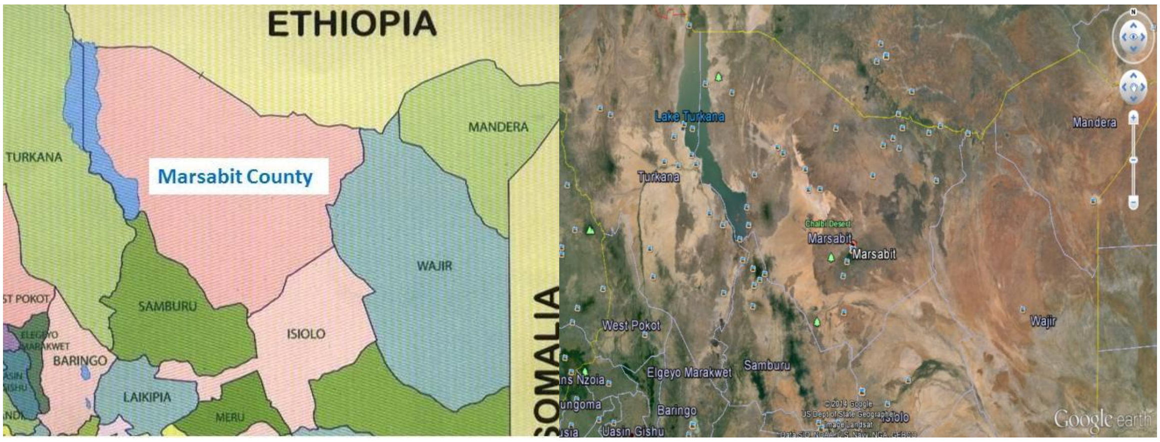

Figure 1 Marsabit County and Google Earth Maps

1.3.2 Livelihood

The population of Marsabit County is around 291,166, where males account for 52 % and women 48 % of the population. The majority of the residents are nomadic pastoralists. Main economic activities/industries are livestock rearing, small- scale fishing, sand harvesting, mining of gems and precious stones, salt mining and small scale trading.

Marsabit County is also endowed with rich natural resources. Lake Turkana (about 85% of this lake is within Marsabit County); South Lake National Reserve which also borders Sibiloi National Park. Sibiloi is the home of KoobiFora which is the world renowned cradle of mankind; wind energy which can be tapped from the region stretching from Arbjahan to the east, all the way through Bubisa, North Horr and Loiyangalani to the west. Reports abound that the energy potential of the County can power the entire East African Community region if harnessed well; Solar energy which the County has immense potential; International border where the County shares over 500 Km of border with Ethiopia, a nation of about 90 million people; mineral potential such as copper, beryl, nepheline, nickel, asbestos, graphite, tourmaline, garnet, iron ore, magnetite, rare earth, talc, chromite, gold and salt among others.

1.3.3 Climate

The County is mainly classified as arid and semi-arid lands (ASAL) which is characterized by warm and hot climate (Edwards, et.al, 1979). The County is generally hot with temperatures ranging from a minimum of 10.1^{o}C to a maximum of 41.4^{o}C. It is also dry most of the year with an annual rainfall varying from 100 mm to 1470 mm. The rainfall pattern and distribution is erratic and unreliable with both time and space. There are two rainfall seasons within a year. Based on Marsabit and Moyale metrological stations 30 years rainfall data analysis, the longest rainy season usually occurs between March and May and short rains between October and December with an annual mean of 680 mm. The driest periods are January, February and September.

1.3.4 Topography

The topography of the County is predominately lowland areas (altitudes ranging from 400 to 700 m.a.s.l.), it is intermingled with several mountain ranges and hills including the Ndoto Mountains (2660 m) in the west, the Hurri Hills (1260 m) in the north, and solitary Marsabit Mountain (1545 m) in the center of the County.

1.4 Scope of the Study

The work involved the assessment of potential areas for flood based farming uses and identification of three or more potential sites in the County. It also proposed improved flood water management practices, knowledge gaps and necessary capacity building strategies. The scope of the services covered all necessary tasks to achieve the objectives, without limiting to the specific activities outlined in the ToR. The detailed and required deliverables of the study are as given below.

- Assess the potential of areas and sites suitable for spate irrigation in Marsabit County, northern Kenya (maps, field visits, interviews with irrigation and agricultural experts)
- Analysis of existent as well as high potential areas for spate and flood irrigation schemes in Marsabit County, together with irrigation and agricultural experts of the respective ministries.
- Analysis of knowledge gaps and capacity development needs of the relevant (agricultural) institutions on County level.
- Report about the findings during field visits and interviews, including risks analysis of failures and problems and how to address/reduce them.
- Recommendations on the way forward, description and calculation of the needs and rough costs of investments for construction, installation, maintenance as well as capacity development of appropriate spate irrigation system at three or more sites in Turkana County,
- Propose appropriate flood water management and use for improving flood water productivity;
- Submit report and maps both in hard and soft copies.

2. HYDROLOGICAL ANALYSIS

Hydrological analysis is fundamental for the designing of safe, stable and economical structures. Determining the design peak discharges and quantifying the volume of water resources available in the basin/catchment are paramount for designing the structures. Although the importance of the analysis is clear and non-debatable, its reliability is often questioned as it is a key factor on the feasibility and sustainability of the project. However, the degree of reliability depends on the availability of long term hydrological data. This however is a major challenge in most parts of Arid and Semi-Arid parts of Africa like Turkana and Marsabit counties. Therefore, the hydrological analysis for the design of flood based farming needs care and cross-checking using several approaches.

Due to the absence of the stream flow data within the visited Lagas, which is common in arid and semi-arid areas, the runoff volume estimations have been undertaken using rainfall-runoff relationship developed by American soil and water conservation (SCS method). This model is basically developed, after several experimental results, for undertaking runoff estimates in ungauged catchments and depends on Curve Numbers. The SCS method is employed to estimate the direct runoff volume of the counties.

To estimate the design peak flood the SCS model needs a daily rainfall data, which is missing for both counties. Therefore, empirical equations practiced in several parts of arid and semi-arid areas of the world have been employed. The empirical equations employed here are developed from an experience of several similar countries of arid and semi-arid parts like Yemen, Botswana, Zimbabwe, South Africa, Namibia and Ethiopia. In addition, elder people of the community have also been interviewed for the frequency and extent of the floods in each site as this is very helpful to cross-check the model results with reality; which is very important in areas where there is shortage of data and problem of data reliability.

2.1 Runoff Volume Estimation

2.1.1 Average and Dependable Rainfalls

The rainfall data from the meteorological station at Marsabit and Moyale are used for the analysis, mainly because of the availability of the long-term monthly rainfall data in the stations. The stations have a monthly rainfall data from 1935 to 2007, which is for 73 years. The monthly average rainfall data for all 73 years data is presented in Figure 2. However, the recent 30 years data have been used for quantifying the potential runoff/flood volume and the 50 % and 75 % dependable rainfall estimates are presented in Figure 3.

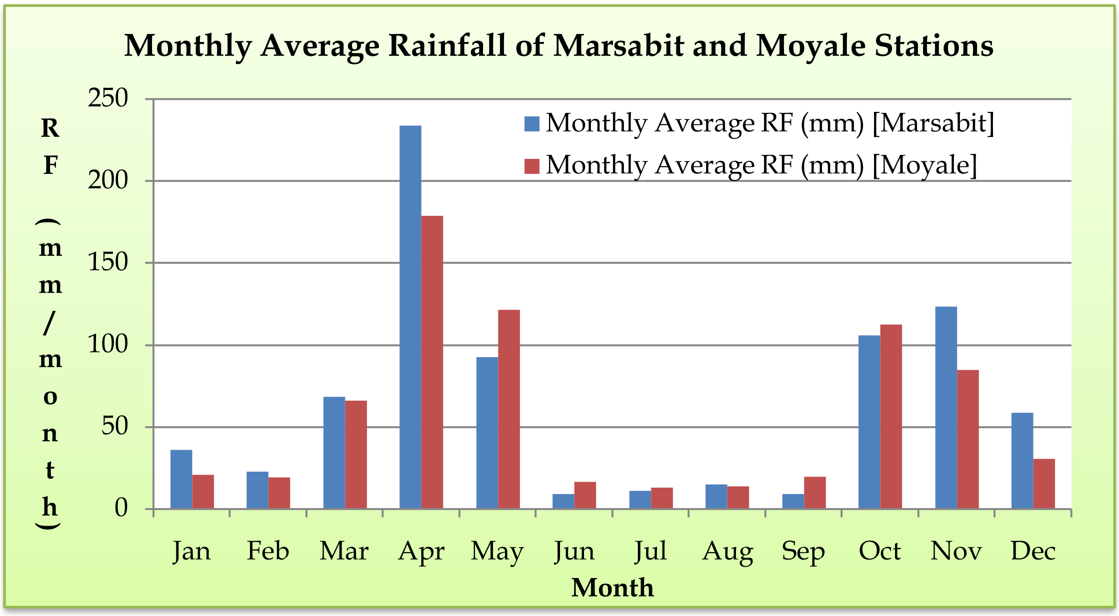

Figure 2 Monthly average rainfall ofMarsabit and Moyale meteorological stations (from 1935 to 2007)

As it can be observed from Figure 2, the long term monthly average rainfall for Marsabit and Moyale metrological stations has bimodal rainfall pattern with peaks in April and November where the largest rainfall occurs during the first season which is between March and May. The second rainfall season is from October to December. The long-term monthly average rainfall peaks are 234 mm in April and 13 mm in July.

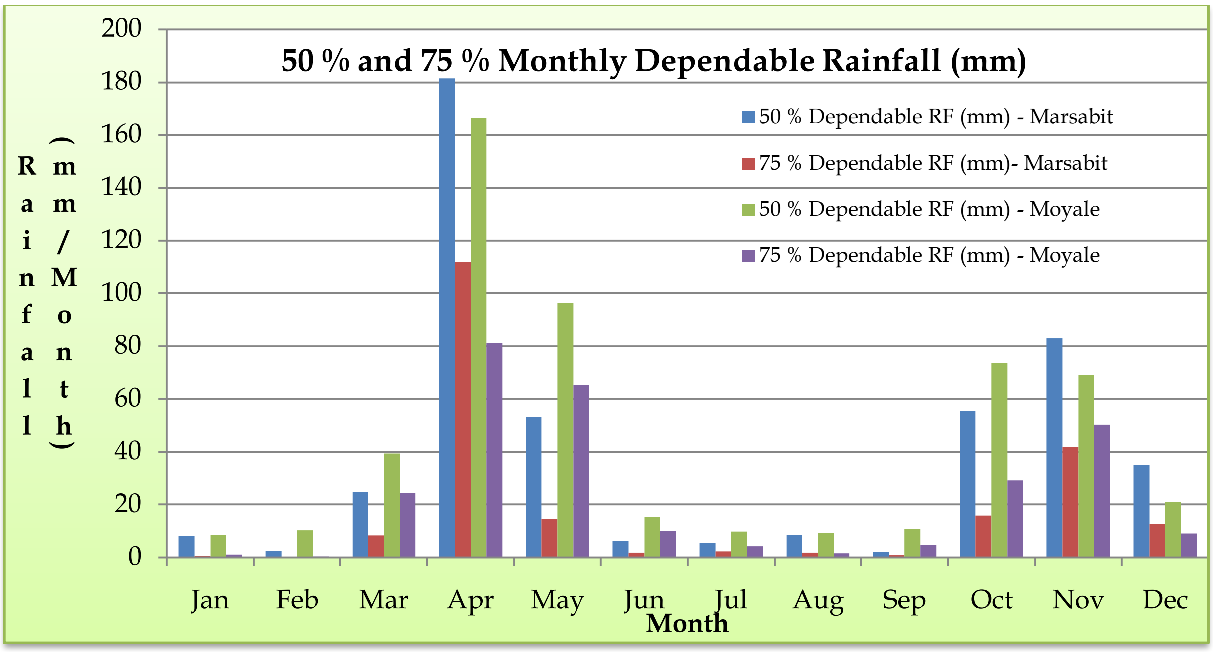

Figure 3 Monthly dependable rainfall of Marsabit and Moyale meteorological stations (from 1980 to 2007)

Figure 3 shows that, the 50 % and 75 % dependable rainfall result of the Marsabit and Moyale stations. As a result, the rainfall in Marsabit with 50 % of probability can occur in both seasons with values of 181 mm and 83 mm, in April (first season) and November (second season) respectively. The rainfall with 75 % probability mainly occur in both seasons with peak values of 112 mm and 42 mm, in April (first season) and November (second season) respectively. Similarly, the result from the analysis from Moyale station shows that with the 50 % probability of rainfall can occur in both seasons with monthly peak values of 166 mm and 73 mm, in April (first season) and October (second season) respectively. The figure, in Moyale station also, shows that with the 75 % probability, rainfall can occur in both seasons with peak values of 81 mm and 50 mm, in April (first season) and November (second season) respectively.

2.1.2 Land Use Land Cover

Land use land cover is also an important parameter which affects the conversion of direct rainfall into runoff. Different literatures have been reviewed in order to retrieve input data for the runoff volume analysis. As it is shown in Figure 4, the land use map extracted from the Mandera triangle, which is developed from the data sources of Kenya, Ethiopia and Somalia, shows that the dominant land uses for both counties are Barren land and bush land (spares). The ground truth from the field observation dictates to accept land use map from the Mandera triangle, for the justification put below. Figure 5 shows pictures taken during the field visit in North Horr, Marsabit County. The pictures show that, the bushes and shrubs concentrate along the banks of the drainage networks of the streams/lagas. The general features are consistent with the land use map of Mandera Triangle. Therefore, for the overall estimation of potential direct runoff depth, weighed land use of 50 % barren land and 50 % bush land is considered. The Curve number values for both barren land and bush land (spares), for hydrological soil group C, are 91 and 77 respectively. Therefore, the weighted average CN will be 84. The table for Curve number is annexed.

Figure 4 Land use map of Marsabitand Turkana counties (Source: Extracted from Land Use Map of Mandera Triangle Area)

Figure 5 Photographs taken during field observation around North Horr, Marsabit, Kenya

2.1.3 SCS-Curve Number Method

The curve number method is the most commonly used method for estimating the volume of runoff generated for every rainfall drop. The CN for each soil type and land use/cover dictates the expected maximum storage of the soil, S. In the SCS-CN method runoff starts after initial abstraction Ia (interception, depression storage and evaporation) has been satisfied. This abstraction comprises principally the interception, surface storage, and infiltration. The ratio of amount of actual retention to the maximum storage is assumed to be equal to the ratio of actual direct runoff to the effective rainfall (total rainfall minus initial abstraction).

Equation (1) shows the assumed relationship in the following mathematical equation.

$$\frac{\mathbf{P - I_a - Q}}{\mathbf{S}} = \frac{\mathbf{Q}}{\mathbf{P - I_a}} \text{............ (Equation 1)}$$

Where: P is total rainfall (mm); Ia is initial abstraction (mm); Q is actual direct runoff (mm); and S is watershed storage (mm).

In the above equation, both parameters (Ia and S) need to be estimated. To eliminate the necessity of estimating both parameters, the relation between Ia and S was developed by analyzing rainfall-runoff data for many small watersheds (CSC, 1972). Generally, Ia is considered to be 20% of the maximum soil storage, S (Equation 2).

$$\mathbf{I_a = 0.2\ S} \text{ .... (Equation 2)}$$

Substituting Equation (2) in Equation (1) gives:

$$\mathbf{Q} = \frac{\mathbf{(P - 0.2S)^2}}{\mathbf{P + 0.8S}} \text{ .... (Equation 3)}$$

Equation (3) is the rainfall-runoff equation used by the SCS method for estimating depth of direct runoff from storm rainfall. The parameter S in Equation (3) is related to CN by:

$$\mathbf{S} = \frac{\mathbf{2540}}{\boldsymbol{CN}} - \mathbf{25.4} \text{ .... (Equation 4)}$$

The storage parameter (S) varies spatially, due to changes in soils, land use/cover and slopes and temporally due to changes in soil water content. As such, the CN method is able to reflect the effect of changes in land use/cover on runoff.

After computing the depth of direct runoff, the weighted runoff depth will be estimated for the watershed for selected daily rainfall events, using Equation (5).

$$Q_{av} = \frac{\sum Q_i A_i}{A} \text{ ………… (Equation 5)}$$

Where: Q_{av} is weighted runoff depth, Q_i is runoff depth for each polygon (mm); A_i is polygon area (km^2) and A is watershed area (km^2).

The direct runoff can be calculated using equation 3. The soil storage (S) can also be calculated using equation 4. Therefore, the Soil storage for the overall area (computed using the average rainfall of the two stations i.e Marsabit and Moyale) will be 4.838 mm.

The computed direct runoff depth for the County is presented in Figure 8 below. The figure shows a monthly direct runoff for any catchment area in the County. The analysis for the potential runoff volume of a given catchment can be easily computed by employing equation 5. The maximum runoff depth is expected to occur during April, with a runoff depth of 168.1 mm and 90.9 mm for 50 % and 75 % dependable rainfall.

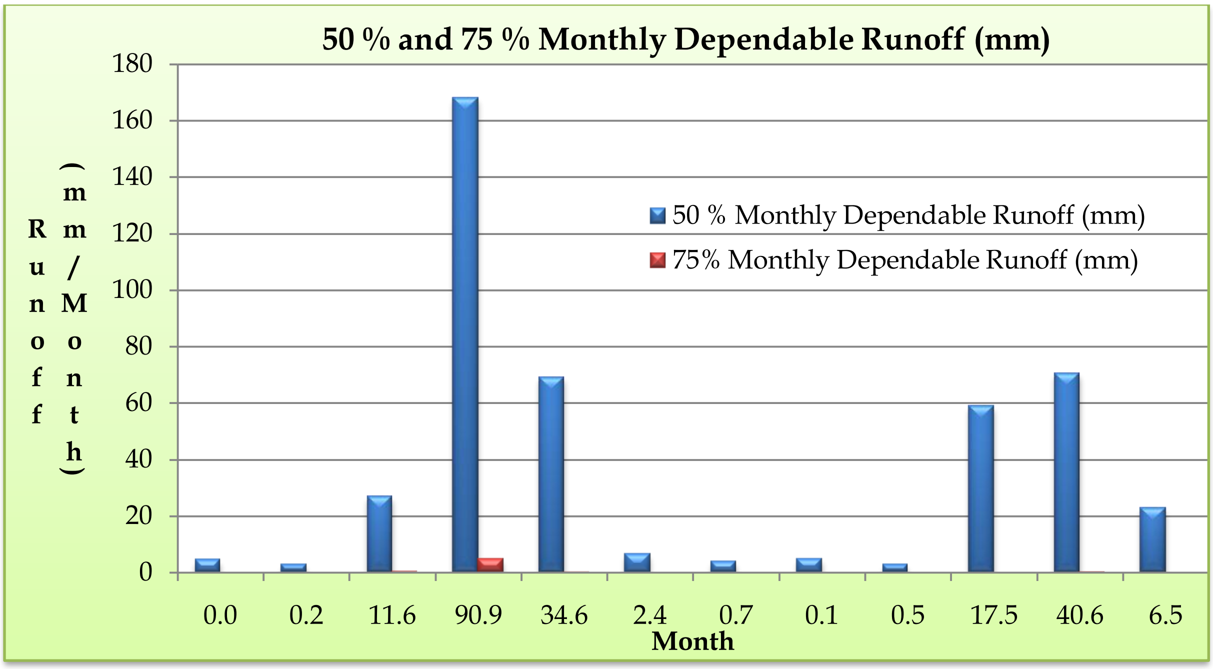

Figure 6 Average Direct Runoff depth of Marsabit County for 50 % and 75% dependable RF

2.2 Peak Flood Estimation

As discussed in section 2.1.1 of the report, the rainfall data obtained from Marsabit and Moyale meteorological stations is only on monthly bases. Therefore, it is not possible to use this data for estimating the peak flood using SCS-Curve Number approach. Under such circumstances, where 24 hours rainfall data records are not available, it is common to use the empirical equations developed in similar areas of arid and semi-arid regions which relate the peak flood with catchment area and other parameters.

2.2.1 Watershed Area Delineation

Defining the catchment characteristics of the watershed area is an important step in computing the runoff for catchments which do not acquire gauging stations. As a result, investigation of the nature of the watershed area has been carried out after the axis is recorded using GPS and the catchment area is delineated using GIS software. The hydrologic characteristics of the catchment such as watershed area, length of the Main River and mean catchment elevation have been investigated. The detail data of the catchment characteristics as presented in the following figures 7 to 9 below.

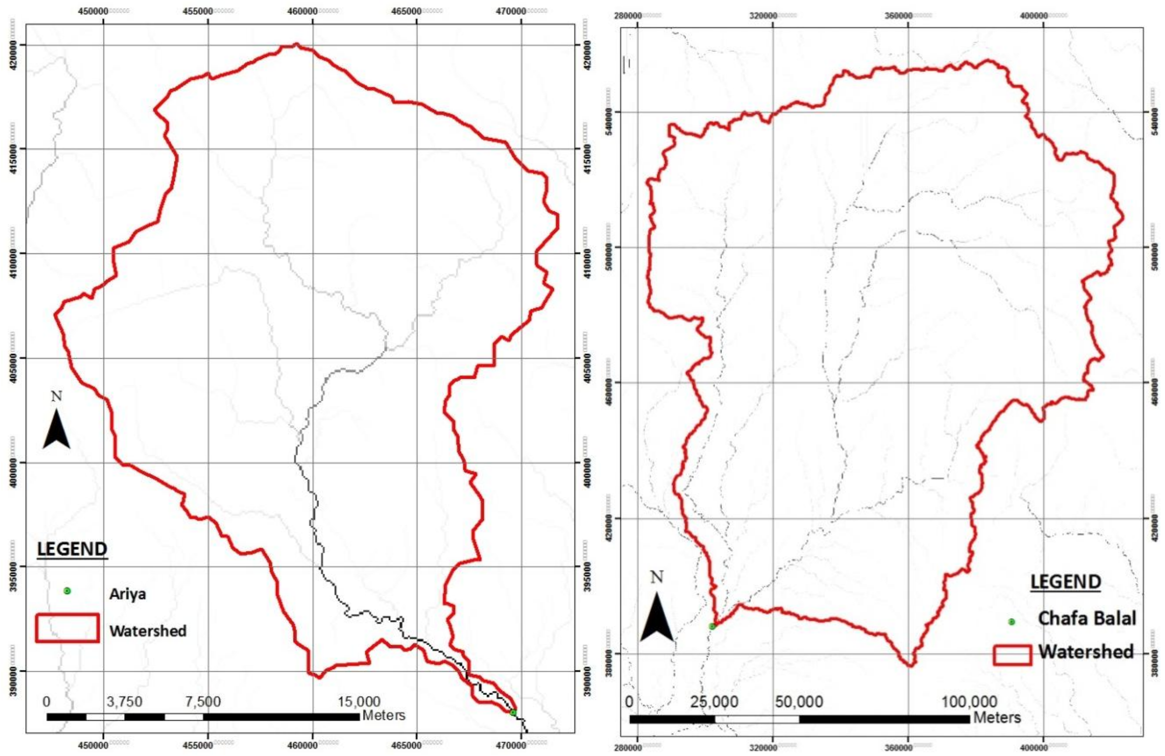

Figure 7 Watershed area of the Ariya and Chafa Balal sites

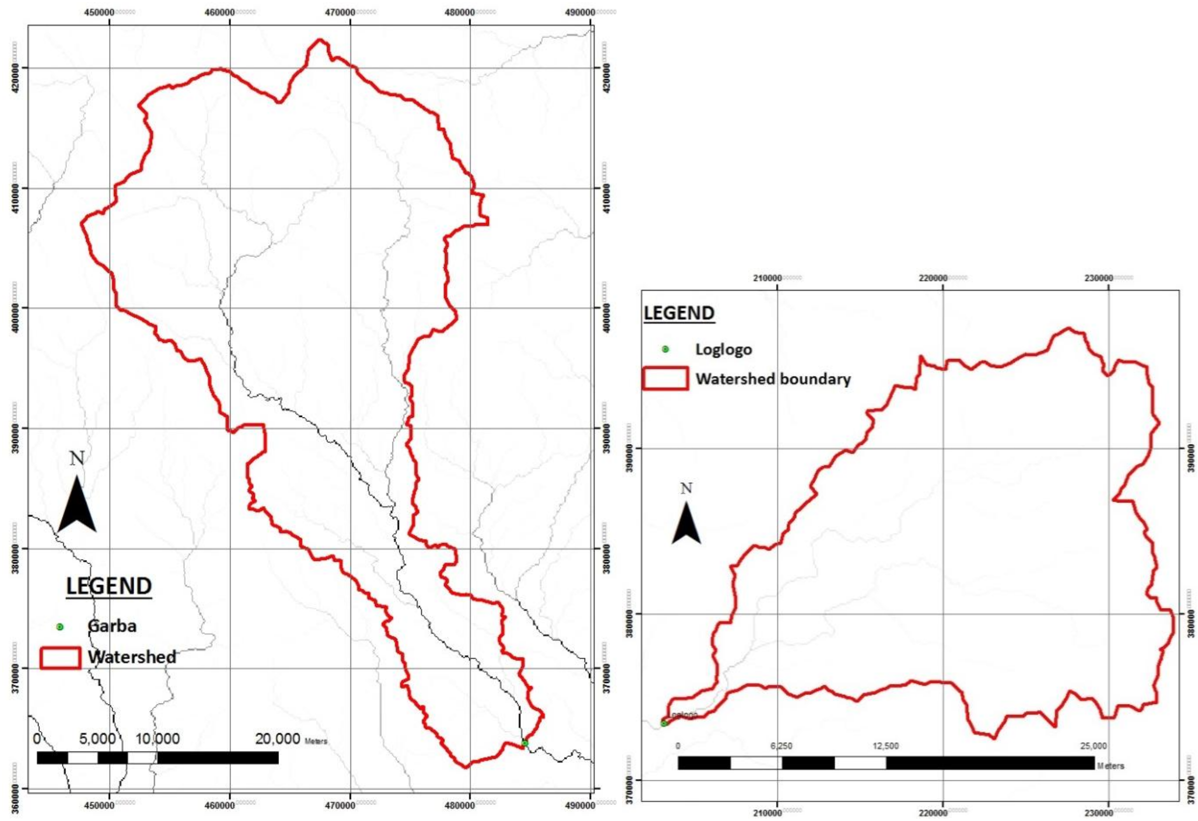

Figure 8 Watershed area of the Garba and Loglogo sites

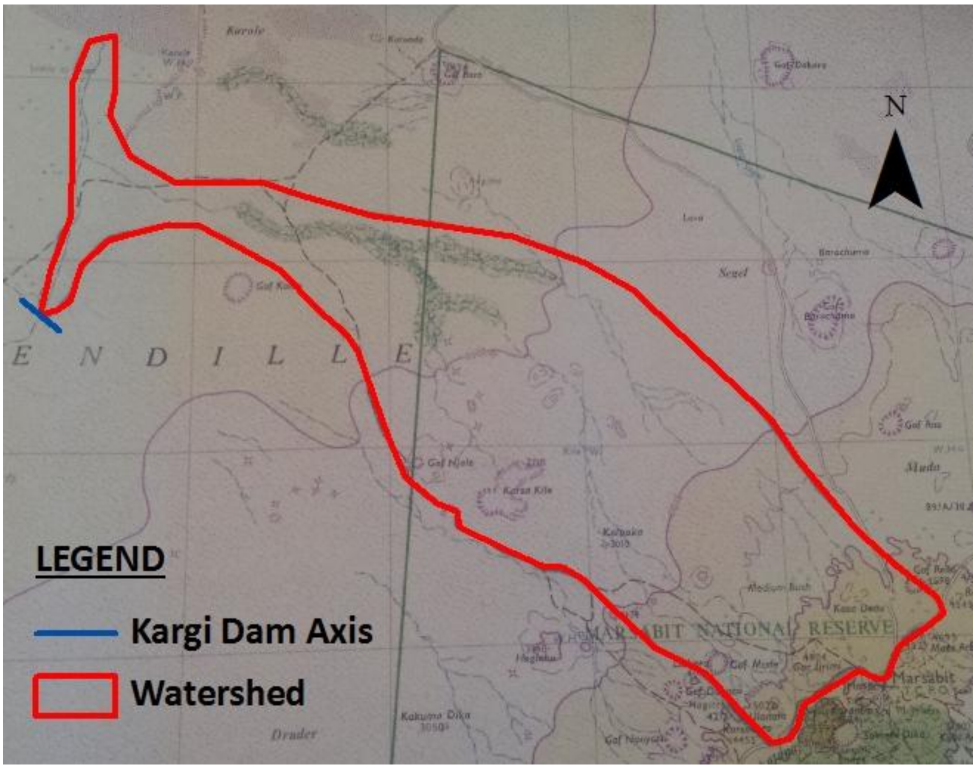

Figure 9 Watershed area of the Kargi site

Table 1 Summary of input data as depicted from GIS and mean rainfall analysis

S. no	Scheme	Input Data			
		Catchment area (Km^2)	Main Stream Length (Km)	Mean Catchment Elevation (masl)	Mean Annual RF (mm)
1	Loglogo	365	37	700	684
2	Garba	810	72	1065	684
3	ChafaBalal	13580	208	1220	684
4	Ariya	355	41	995	684
5	Kargi	420	57	865	684

2.2.2 Peak Flood Estimation Using Empirical Methods

Empirical equations which are functions of mean annual rainfall, catchment area and mean elevation/altitude of the catchment have been used to estimate the peak flood. Table 2 presents, summary of six design discharge computation methods.

Table 2 Summary of Empirical formulas for estimating the peak flood (FAO 2010 and Tekeze Basin Master Plan Study, 1980)

S. no	Method	Formula	Remarks
1	Binnie (1988)	$MAF = 3.27 *A^{1.163}*MSL^{-0.935}$	Regional flood formula developed for wadis in Southern Yemen but probably OK in the Red Sea region
2	Bullock (1993)	$MAF = 0.114 *A^{0.52}*MAP^{0.537}$	Developed using data from 43 semi-arid catchments in Botswana, Zimbabwe, South Africa and Namibia
3	Nouh (1988)	$MAF = 0.322*A^{0.56*}ELEV^{0.44}$	Developed from regressions on data from 26 gauging stations
4	Farquharson et al. (1992)	$MAF = 0.172*A^{0.57*}MAP^{0.42}$	Developed from 3,637 station years of data collected from arid zones worldwide
5	Dr. Admasu's Formula	$Q_p =1+5A^{-0.2}* 0.878A^{0.7}$	Developed from many small gauged stations in Ethiopia
6	Tekeze Basin Formula	$Q_p = A*33.33A^{-0.609}$	Developed during the master plan study of the Tekeze Basin in Ethiopia

Where,

MAF = Mean annual flood peak discharge (m^3/s)

A = Catchment area (km^2)

ELEV = Mean catchment elevation (m)

MSL = Main stream length (km)

MAP = Mean annual precipitation (mm)

Qp = Annual flood peak discharge (m^3/s)

Table 3 Peak flood of the schemes/sites identified in Marsabit County

S.no	Scheme	Mean Annual Peak Flood Estimation method (m^3/s)							
		Binnie (1988)	Bullock (1993)	Nouh (1988)	Farquharson et.al.	Dr. Admasu	Tekeze Basin	Average	Max
1	Loglogo	100	82	157	77	138	335	148	335
2	Garba	134	124	294	121	220	457	225	457
3	ChafaBalal	1294	535	1515	605	1198	1377	1087	1515
4	Ariya	88	80	180	76	136	331	149	331
5	Kargi	78	88	186	83	150	354	156	354

Therefore, the result obtained by the six methods is presented in Table 3. Therefore, the average of the six methods is considered as a design peak flood of the schemes.

3. SOILS AND AGRONOMY

3.1 Soils

The soil types of the potential spate irrigation sites visited in Marsabit County are generally similar. While the exact soil textural classification of the specific sites will be determined in laboratory during the detailed feasibility study and design, the reconnaissance survey has revealed a top 15 cm of sandy soil underlain by loam soil. This arrangement has a positive implication from water management point of view. The top sand texture will encourage high infiltration while the underneath loam soil will enable a storage of sufficient moisture for the crop growth.

3.2Crops and Cropping Pattern

According to the information from the experts and the local community, the major crops grown in the County are maize, sorghum and cowpeas in order of land coverage. The existing cropping pattern of the agro-pastoralists is proposed to be grown in the envisaged spate irrigation scheme (Table 4). The sowing date of the proposed crops is also the same as that of the agro-pastoralists. This is due to the fact that sowing in spate irrigation depends either on the onset of rainfall in the area or on the flood coming from the highlands. No one could be as experienced as the local farmers in adapting the sowing time to the climate variability. As it can be seen from the Table, the crops growing in the area are short duration crops which are suitable to water scarce arid and semi-arid areas.

Table 4 Proposed cropping pattern for the study area during the main rainy season

Crop	Area (%)	Sowing date	Growing period (Days)
Maize	50	April 01	90
Sorghum	30	April 01	90
Cowpea	20	April 01	70

3.3 Crop and Irrigation Water Requirement

The crop and irrigation water requirement of the potential spate irrigation schemes was determined using the **CROPWAT 8** computer software developed by FAO (Swennenhuis, et al, 2009). **CROPWAT 8** is a computer program that can calculate crop and irrigation water requirements and irrigation scheduling from climatic, soil and crop data. The program is interactive in nature and can execute the following tasks very quickly:

- Calculates the potential evapotranspiration (ETo) based on monthly climatic data;
- Calculates the crop water requirements on a decade (10-day) basis based on ETo and crop data;
- Calculates effective rainfall based on dependable rainfall data; and
- Calculates the irrigation water requirement and irrigation scheduling based on crop data, soil data and the selected irrigation scheduling criteria.

3.3.1 Potential Evapotranspiration

The influence of the climate on crop water need is given by the potential evapotranspiration or reference crop evapotranspiration (ETo). ETo is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water. The CROPWAT 8 software employs the FAO Penman-Monteith method for determining reference crop evapotranspiration (ETo). This method overcomes the shortcomings of all other empirical methods and provides ETo values that are more consistent with actual crop water use data in all regions and climates and is now the sole recommended method. This method calculates the ETo of an area based on the temperature, humidity, wind speed and sunshine data. Unfortunately, the available climatic data for the study area are only maximum and minimum temperatures. However, the CROPWAT 8 software also gives better estimated ETo values for such areas by extrapolating the missing climatic data from its built-in global database based on the location (Latitude and longitude) and altitude of the site. Table 5 presents the potential evapotranspiration of the study area calculated by this software. As it can be seen, the average minimum ETo of the study area is 3.14 mm/day in November while the maximum is 4.16 mm/day in March.

Table 5 Potential evapotranspiration (ETo) of the study area

Month	Min. temp (^oC)	Max. temp (^oC)	Humidity (%)	Wind speed (m/s)	Sunshine (Hrs)	Solar Radiation ($MJ/m^2/day$)	ETo (mm/day)
January	16.5	25.6	79.0	2.0	6.2	18.1	3.64
February	16.8	26.9	77.0	2.0	6.9	19.9	4.07
March	17.5	27.2	78.0	2.0	6.7	19.9	4.16
April	17.3	25.5	80.0	2.0	5.7	18.0	3.68
May	17.0	25.5	80.0	2.0	5.9	17.6	3.59
June	15.6	24.6	79.0	2.0	6.3	17.5	3.50
July	14.4	23.7	78.0	2.0	6.5	18.0	3.47
August	14.5	24.4	77.0	2.0	6.9	19.4	3.74
September	14.9	25.5	76.0	2.0	7.3	20.6	4.06
October	16.3	25.0	79.0	2.0	6.0	18.5	3.68
November	17.0	23.9	83.0	2.0	4.7	15.9	3.14
December	16.9	24.7	81.0	2.0	5.3	16.5	3.29
Average	**16.2**	**25.2**	**78.9**	**2.0**	**6.2**	**18.3**	**3.67**

3.3.2 Crop and Irrigation Water Requirement

Crop water requirement **(ETc or CWR)** is the quantity of water required by a crop in a given period of time for its normal growth under field condition at a specific place. Under the same climatic conditions, different crops require different amounts of water and the quantities of water used by a particular crop vary with its stage of growth. The actual amount of water required by a crop can be calculated by the following equation:

ETc = ETo * Kc

Where:

ETc = Crop water need (mm/unit time)

ETo = Reference crop evapotranspiration (mm/unit time) [Influence of climate]

Kc = Crop factor (mm/unit time) [Influence of crop type and growth stage]

Water demand of the various crops proposed for the visited sites was determined by CROPWAT 8 software on a decade (10-day) basis by using ETo and crop data as input. The major crop data required for the determination of ETc include crop type, planting date and growing season. Table 6 presents the crop water requirement of the study area during the main crop growing season. The crop water demand during the entire growing period in the area ranges from a **199.40 mm** for cowpea to **251.30** mm for maize.

Table 6 Crop water requirement of the study area during the main growing season

Crop	Month	March			April			May			Total
	Decade	D1	D2	D3	D1	D2	D3	D1	D2	D3	
Maize	Stage	Init	Deve	Deve	Deve	Mid	Mid	Late	Late	Late	
	Kc	0.30	0.35	0.66	1.01	1.16	1.16	1.10	0.79	0.48	
	ETc (mm/dec)	11.5	12.9	24.0	36.1	41.3	45.0	38.2	27.3	15.0	**251.30**
Sorghum	Stage	Init	Deve	Deve	Deve	Mid	Mid	Late	Late	Late	
	Kc	0.30	0.34	0.58	0.85	0.97	0.97	0.96	0.82	0.60	
	ETc (mm/dec)	11.5	12.5	21.0	30.3	34.2	37.3	33.6	28.3	18.8	**227.50**
Cowpea	Stage	Init	Init	Deve	Deve	Mid	Late	Late			
	Kc	0.50	0.50	0.65	0.91	1.03	1.03	0.94			
	ETc (mm/dec)	19.2	18.4	23.5	32.6	36.5	39.7	29.5			**199.40**

The water demand of crops can be supplied by either rainfall, irrigation or a combination of both. The net irrigation water requirement of a certain crop is the difference between the crop water requirement and part of the rainfall which can be used by the crop (the effective rainfall, Pe). Not all rainfall is effective; part may be lost by surface runoff, deep percolation or evaporation. Effective rainfall is the part of rainfall that is stored in the root zone. There are various approaches that can be used to estimate the effective rainfall from the total monthly rainfall. However, the following formula was developed by FAO based on analysis carried out for different arid and sub-humid climates and is more suitable for Marsabit County.

$$Pe = 0.6\,P_{dep} - 10 \qquad \text{for } P_{dep} < 70 \text{ mm.}$$

$$Pe = 0.8\,P_{dep} - 24 \qquad \text{for } P_{dep} > 70 \text{ mm.}$$

Where:

Pe = Monthly effective rainfall (mm)

Pdep = Monthly dependable rainfall (mm)

The net irrigation water requirement of the study area was also determined by the CROPWAT 8 software. The software first estimates the effective rainfall using the above formula and calculates the net irrigation water requirement by subtracting the effective rainfall from the crop water requirement.

Finally, the gross irrigation water requirement and duty of the study area was determined taking into account the cropping pattern and corresponding area coverage, the irrigation efficiency and the daily operation hours of the irrigation scheme. As it is known, irrigation efficiency accounts the losses of water incurred during conveyance, distribution and application to the field and was considered 50% for the study area. Moreover, the average daily project operation hour was taken as 8 hours taking into account the local spate hydrology.

The crop water requirement and net irrigation water demand of the main crop growing season and the corresponding gross discharge (Duty) required for the study area are given in table 7 and table 8. Table 7 gives the duty required taking effective rainfall into account while table 8 presents the demand if effective rainfall is not considered. Since there is no guarantee regarding the simultaneous occurrence of rainfall in the lowlands and flood from the highlands, it is generally recommended to design the system by excluding effective rainfall. However, the results show that the maximum duty requirement is 2.89 l/s/ha for both with and without effective rainfall scenario clearly indicating the insignificance of rainfall during the peak demand period. The result shows that the contribution of rainfall to crop development is vital during the early growth stages of the crop only. At later stage, flood supply is the only option to ensure sustainability of the crop and optimum yield.

Table 7 Crop water requirement and net and gross irrigation requirement of the study area taking into account effective rainfall

Crop			Month	March			April			May		
			Decade	D1	D2	D3	D1	D2	D3	D1	D2	D3
	Area (%)	Parameter	Unit									
Maize		ETc	mm/decade	11.5	12.9	24.0	36.1	41.3	45.0	38.2	27.3	15.0
		Peff	mm/decade	16.3	24.5	16.3	0.1	0.0	0.0	0.0	0.0	0.0
		Net. Irr (Ic)	mm/decade	0.0	0.0	7.7	36.0	41.3	45.0	38.2	27.3	15.0
		Area (Ac)	....	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	50	Ic.Ac	mm/decade	**0.0**	**0.0**	**3.9**	**18.0**	**20.7**	**22.5**	**19.1**	**13.7**	**7.5**
Sorghum		ETc	mm/decade	11.5	12.5	21.0	30.3	34.2	37.3	33.6	28.3	18.8
		Peff	mm/decade	16.3	24.5	16.3	0.1	0.0	0.0	0.0	0.0	0.0
		Net. Irr (Ic)	mm/decade	0.0	0.0	4.7	30.2	34.2	37.3	33.6	28.3	18.8
		Area (Ac)	....	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	30	Ic.Ac	mm/decade	**0.0**	**0.0**	**1.4**	**9.1**	**10.3**	**11.2**	**10.1**	**8.5**	**5.6**
Cowpea		ETc	mm/decade	19.2	18.4	23.5	32.6	36.5	39.7	29.5	0.0	0.0
		Peff	mm/decade	16.3	24.5	16.3	0.1	0.0	0.0	0.0	0.0	0.0
		Net. Irr (Ic)	mm/decade	2.9	0.0	7.2	32.5	36.5	39.7	29.5	0.0	0.0
		Area (Ac)	....	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0
	20	Ic.Ac	mm/decade	**0.6**	**0.0**	**1.4**	**6.5**	**7.3**	**7.9**	**5.9**	**0.0**	**0.0**
Net irrigation requirement			mm/decade	0.6	0.0	6.7	33.6	38.2	41.6	35.1	22.1	13.1
Project efficiency			%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Gross irrigation requirement			mm/decade	**1.16**	**0**	**13.4**	**67.12**	**76.42**	**83.26**	**70.16**	**44.28**	**26.28**
Net irrigation area			ha	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Project supply requirement			mm/day/ha	0.116	0	1.34	6.712	7.642	8.326	7.016	4.428	2.628
			m3/day/ha	1.16	0	13.4	67.12	76.42	83.26	70.16	44.28	26.28
Hours of opreration per day			hr	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Ratio hours of application			hr/24hr	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Actual project supply requirement			m3/day/ha	3.48	0.00	40.20	201.36	229.26	249.78	210.48	132.84	78.84
			l/s/ha	0.04	0.00	0.47	2.33	2.65	2.89	2.44	1.54	0.91
Maximum duty for design			l/s/ha	**2.89**								

Table 8 Crop water requirement and net and gross irrigation requirement of the study area without considering effective rainfall

Crop			Month	March			April			May		
			Decade	D1	D2	D3	D1	D2	D3	D1	D2	D3
	Area (%)	Parameter	Unit									
Maize		ETc	mm/decade	11.5	12.9	24.0	36.1	41.3	45.0	38.2	27.3	15.0
		Peff	mm/decade	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Net. Irr (Ic)	mm/decade	0.0	0.0	24.0	36.1	41.3	45.0	38.2	27.3	15.0
		Area (Ac)	....	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	50	Ic.Ac	mm/decade	**0.0**	**0.0**	**12.0**	**18.1**	**20.7**	**22.5**	**19.1**	**13.7**	**7.5**
Sorghum		ETc	mm/decade	11.5	12.5	21.0	30.3	34.2	37.3	33.6	28.3	18.8
		Peff	mm/decade	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Net. Irr (Ic)	mm/decade	0.0	0.0	21.0	30.3	34.2	37.3	33.6	28.3	18.8
		Area (Ac)	....	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	30	Ic.Ac	mm/decade	**0.0**	**0.0**	**6.3**	**9.1**	**10.3**	**11.2**	**10.1**	**8.5**	**5.6**
Cowpea		ETc	mm/decade	19.2	18.4	23.5	32.6	36.5	39.7	29.5	0.0	0.0
		Peff	mm/decade	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Net. Irr (Ic)	mm/decade	19.2	0.0	23.5	32.6	36.5	39.7	29.5	0.0	0.0
		Area (Ac)	....	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0
	20	Ic.Ac	mm/decade	**3.8**	**0.0**	**4.7**	**6.5**	**7.3**	**7.9**	**5.9**	**0.0**	**0.0**
Net irrigation requirement			mm/decade	3.8	0.0	23.0	33.7	38.2	41.6	35.1	22.1	13.1
Project efficiency			%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Gross irrigation requirement			mm/decade	**7.68**	**0**	**46**	**67.32**	**76.42**	**83.26**	**70.16**	**44.28**	**26.28**
Net irrigation area			ha	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Project supply requirement			mm/day/ha	0.768	0	4.6	6.732	7.642	8.326	7.016	4.428	2.628
			m3/day/ha	7.68	0	46	67.32	76.42	83.26	70.16	44.28	26.28
Hours of opreration per day			hr	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Ratio hours of application			hr/24hr	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Actual project supply requirement			m3/day/ha	23.04	0.00	138.00	201.96	229.26	249.78	210.48	132.84	78.84
			l/s/ha	0.27	0.00	1.60	2.34	2.65	2.89	2.44	1.54	0.91
Maximum duty for design			l/s/ha	**2.89**								

3.4 Irrigation Scheduling for Marsabit

Irrigation scheduling indicates how much irrigation water has to be given to the crop and how often or when this water is given. The amount of water which can be given during one irrigation application depends on the soil type and the crop root depth. The soil type influences the maximum amount of water which can be stored in the soil per meter depth. Sand can store only a little water and has low moisture holding capacity. Irrigation water has, therefore, to be applied in small amount but more frequently on sandy soils. On the other hand, clay has high available water content and larger amounts can be given less frequently.

The root depth of a crop also influences the maximum amount of water which can be stored in the root zone. If the root system of a crop is shallow, little water can be stored in the root zone and frequent but small irrigation applications are needed. With deep rooting crops, more water can be taken up and more water can be applied less frequently. Young plants have shallow roots compared to fully grown plants. Thus, just after planting or sowing, the crop needs smaller and more frequent water applications than when it is fully developed.

The CROPWAT 8 software can be used for the determination of irrigation scheduling of schemes. The most important soil data required by the CROPWAT 8 for scheduling is the amount of water that can be stored in a soil profile, termed as Total Available Moisture (TAM). The total available moisture (TAM) is the difference in moisture content of the soil between the Field Capacity (FC) and Permanent Wilting Point (PWP). Its amount is determined by the relationship between the Volumetric Soil Moisture Content (SMC), which represents the liquid phase in the soil volume, and the Soil Water Pressure (SWP) which is a measure of the matric forces by which the water is retained in the soil. For this purpose, disturbed and undisturbed soil samples have to be collected from representative locations and depths in the specific schemes and laboratory analysis carried out during the detailed feasibility and design study.

However, it has to be noted that the CROPWAT 8 software usually determines the amount of irrigation water required at 10 days interval based on the soil moisture holding capacity data, the crop root zone and the selected irrigation scheduling criteria. In short, the software will simply decide how much irrigation needs to be supplied to the crop every decade. This can, however, be satisfied if there is sufficient and continuous supply of water available during the crop growing period. This can generally work well if the source of water supply is either dam or a perennial river flow. Unfortunately, flood is not exactly known when it will occur during the crop growing season and, hence, the use of this conventional irrigation scheduling technique without considering the nature of spate is inappropriate.

Devising a scheduling approach suitable for spate irrigation is, therefore, very crucial. As a result, the irrigation scheduling for the study area has to be determined using CROPWAT 8 software using the following scheduling criteria:

- Available soil moisture of 50%TAM should be assumed just prior to the time of sowing.
- Applying irrigation water to the crop (refilling the crop root zone to field capacity) after 80% of the Readily Available Moisture (RAM) in the root zone is extracted by the crop. This is purposely set to avoid water stress of the crops as a result of the unknown flood occurrence in the area. These scheduling criteria will, therefore, allow an extension of the irrigation interval up to 20% without affecting the crop and will act as a contingency for delays in flood occurrence.
- Effective rainfall should not be accounted in the determination of the scheduling. Any effective rainfall that occurs within the irrigation interval will, therefore, be an additional contingency provision to the above thereby improving the reliability of the scheduling.
- Field application efficiency of 60 % or less should be assumed since irrigation water management is at its early stage.

4. TECHNICAL INVESTIGATION OF THE SITES

The technical investigation has been done based on the data collected during the field visit. More than five sites have been visited and their location, suitability with respect to implementing flood based farming, available flood frequency, duration and depth, available command area, irrigation capacity and rough estimate of project implementation cost is presented for each site.

4.1 Loglogo

The field research was attended by multidisciplinary team members that included experts from local organizations such as the Ministry of Water, Agriculture and Livestock, GIZ Marsabit, Sub-County administrator and community representatives. From the discussion with the community representatives and other stakeholders, it was learnt that, the interestof the community is massive.

4.1.1 Location

Loglogo is administratively and geographically located as

- Administrative Location
  - County: Marsabit
  - Sub-County: Laisamis
  - Ward:
  - River/Laga: Milgis
- Geographical location (GPS reference, UTM- WGS 1984)
  - Easting: 37N 0373315
  - Northing: 0202999
  - Altitude: 493 m.a.s.l

4.1.2 Suitability of the Site with Respect to Flood Based Farming Systems

Milgis is an ephemeral river crossing the road connecting Isiolo and Marsabit. This site is suitable for diverting the flood using spate irrigation. The site is located upstream of the culvert through which the river is crossing the road. There is a dam which is constructed upstream of the culvert. The name of the dam is Maralal, which spills to this river. The sources of the water mainly originate from Ndotto and Nyiro ridge.

Another possible site location for the diversion of the flood is also located at Easting of 37 N 0371004 and Northing of 0201756. The cross-section of the river diversion location has an approximate value of 20 m width and 3 m depth. The command area can be immediately downstream of the road, for agricultural practice, or far downstream which may serve as a source of water for the rangeland development. The flood plain is located very far downstream with Easting of 37 N 0389308 and Northing of 0202454.

Figure 10 Site selected suitable for Spate irrigation in the MelgisLaga

4.1.3 Floods

The Rainfall characteristic of the river is a bi-modal. The first rain season, shortest, is from March to May and the second rain season, longest, is from mid-October to December. According to an interview with the elder people in the area, the flood is overtopping the bank level during good rain season.

4.2 ChafaBalal

In this scheme also, it can easily be observed that, the interest of the community is massive. Further discussions were also undertaken with the community representatives and administrators and other stakeholders to ensure the interest.

4.2.1 Location

ChafaBalal is administratively and geographically located as

- Administrative Location
    - County: Marsabit

- Sub-County: North Horr
- Ward: Maikona
- River/Laga: ChafaBalal

• Geographical location (GPS reference, UTM- WGS 1984)
  - Easting: 37N 0305387
  - Northing: 0386825
  - Altitude: 439 m.a.s.l

4.2.2 Suitability of the Site with Respect to Flood Based Farming Systems

Three possible flood diversion sites have been observed during the field research visit. All the three sites are suitable for diverting the flood using spate irrigation. The location of each site is presented sequentially starting from the upstream moving downstream. Location of the 1st option is Easting 37 N 0305387 Northing 0386825 and an altitude of 439 masl. Location of the 2nd option is Easting 37 N 0305625 Northing 0386311 and an altitude of 440 masl. The location of the 3rd option is Easting 37 N 0305533, Northing 0386025 and an altitude of 438 masl. The location of the grazing land, possible command area, is Easting 37 N 0306339 Northing 0385289 and an altitude of 442 masl.The location of the road is Easting 37 N 0306233 Northing 0370444 and an altitude of 405 masl.

An approximate average cross-section of the river diversion location is 20 to 25 m in width by 2 m in depth at the first option and 20/30 m in width by 2 m in depth at the second option. There are people living near the downstream of the command area. The location of the village is Easting 37 N 0309440 Northing 0367239 and an altitude of 398 masl. The population size of the village is estimated to be between 1600 HH and 2000HH.

Figure 11 Two of the three potential spate irrigation sites at Chafa Balal

4.2.3 Floods

The Rainfall characteristic of this river is a bi-modal. The first rain season, shortest, is from March to May and the second rain season, longest, is from mid-October to December. According to interview held with the elder people in the area, the flood is overtopping the bank level during good rain season. The sources of flood for this site are the Konso and Warera mountains of the Ethiopian highlands. The maximum number of flood occurrence per year is four times. The minimum number of flood occurrence per year is one or two. Common/average number of flood occurrence per year is three. The duration of the flood is two up to three days when the rain is small and one week when the rain is good.

4.3 Garba

In this scheme also, it can easily be observed that, the interest of the community is immense. The administrators/leaders of the community have shown a great interest to develop their area. Site selection was highly supported by the leaders of the community, which is really very important aspect for introducing the technology.

4.3.1 Location

Garba is administratively and geographically located as

- Administrative Location
  - County: Marsabit
  - Sub-County: Moyale
  - Ward: Obbu
  - River/Laga: Garba
- Geographical location (GPS reference, UTM- WGS 1984)
  - Easting: 37N 0484662
  - Northing: 0363877
  - Altitude: 626 m.a.s.l

4.3.2 Suitability of the Site with Respect to Flood Based Farming Systems

The field visit was resumed through stop over to an existing check dam. The location of the check dam is Easting 37 N 0484662 Northing 0363877 and an altitude of 626 masl. According to the community leaders, their water resources development priority is for forage production and livestock water supply.

The crest length of the existing check dam, which was constructed for serving as water supply source to the livestock, is 30 m. The top crest width of the check dam is 30 cm. The width (along the cross-section) of river just upstream of the check dam is 9 m and bout 2.5 m in deep. The check dam is bypassed by the flood in the left side of the bank looking downstream. The current Population estimate that can be served from this site is 7,000-8,000 people.

Figure 12 Existing check dam and the laga at its immediate downstream

4.3.3 Floods

The rainfall is bi-modal and it flows continuously during the rain seasons. The first season is the longest and it is from March to May. The second season, short, is from October to December. The source of the flood is Dukale and Gotu mountains of the Ethiopian highlands.

4.4 Ariya

In this scheme also, it can easily be observed that, the interest of the community is immense. The administrators/leaders of the community have shown incredible interest to develop their area. Site selection was highly supported by the leaders of the community, which is very important aspect for introducing the technology.

4.4.1 Location

Ariya is administratively and geographically located as

- Administrative Location
    - County: Marsabit
    - Sub-County: Moyale
    - Ward: Obbu
    - River/Laga: Ariya
- Geographical location (GPS reference, UTM- WGS 1984)
    - Easting: 37N 0468143
    - Northing: 0387329
    - Altitude: 686m.a.s.l

4.4.2 Suitability of the Site with Respect to Flood Based Farming Systems

The source of the water is from highlands of Ethiopia. The site is suitable for road water harvesting type of structure where the flood water passing through the road culverts in the main highway of Addis – Moyale – Nairobi can be diverted towards the nearby command area. There are 25 rectangular culverts within 2068 m. The number of opening of the culverts ranges from one to about 6 per culvert. Most of the culverts have only one opening. This site can be considered as an ideal site to practice a flood-based farming without investing on the headwork. The site needs mainly land preparation immediately downstream of the road. The development options of this site could also be for fodder and crop productions and livestock water supply.

Figure 13 Picture taken at the Ariya culverts and adjacent areas

4.4.3 Floods

The source of the flood is highlands of Ethiopia crossing the road connecting Nairobi - Moyale - Addis Ababa. The flood is distributed in to the flood plain area where it passes through 25 rectangular culverts and this site can be considered as best opportunity to reduce the investment cost.

4.5 Kargi

This site is unique with respect to flood based farming practice; the site is suitable for storing floods in a dam. There is a possibility of constriction of small dam as it is located in a very narrow valley, which makes it economical. In addition, there is an interest from the community to introduce irrigation of the land to cultivate vegetables and other crops. Furthermore, water supply for the livestock is also required.

4.5.1 Location

Kargi is administratively and geographically located as

- County: Marsabit
    - Sub-County: Laisamis
    - Ward: Kargi/Soth Horr
    - River/Laga: Kargi
- Geographical location of the flood plain area (GPS reference, UTM- WGS 1984)
    - Easting: 37N 0346251
    - Northing: 0277783
    - Altitude: 411 m.a.s.l

4.5.2 Suitability of the Site with Respect to Flood Based Farming Systems

The site is suitable for construction of small dam. The dam axis location is Easting 37N 0345893 and Northing 0275008 with altitude of 429 m. The dam axis has a width of 18 and 30 m at its bottom and top sides respectively and a height of 15 m. The command area which is a flood plain area (located at, Easting 37N 0346251 and Northing 0277783 with altitude of 411 m.a.s.l and an immediate downstream of the dam site) is approximated to be 200 ha. The dam site is 83 km from Marsabit. In this site also, there is an interest from the community to introduce irrigation of the land to cultivate fodder and other crops. Furthermore, water supply for the livestock is also required.

Figure 14 The dam axis and its reservoir area at Kargi

4.6 Command area Determination

The aim of the study is to provide a dependable spate irrigation system within the schemes using recent engineering design methods, the amount of runoff that has to be diverted should be enough to irrigate a scheme size to be developed. Therefore, an appropriate estimate of the diverted flood must be handled with optimum cost of the project. This can be described in terms of either the ratio of diverted discharge to the total river flood. The runoff diversion ratio is assumed to be determined by referring to the already established value of other countries by considering the actual condition of the site into account. In this scheme however, there is no available data on the diversion efficiency. In the previously constructed spate systems in Ethiopia, diversion ratio of 0.6 up to 1 is adopted. According to the local condition of the sites and to be on the safest side, runoff diversion ratio of 0.5 is adopted.

For the purpose of effective comparison, the command area determination has been done using both the 75 % and 50 % dependable rainfall. The result is as presented in table 9.

Table 9 Command area determination for all schemes

S.no	Sites	Catchment area (Km2)	Dependable RF	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Irrigable Area (ha)
1	Loglogo	365	50%	1612409	1020455	9817012	61347765	25255153	2356548	1399750	1782807	1006355	21475741	25727883	8315505	161117383	2895
			75%	5720	69200	4236787	33188535	12621579	881388	257265	22839	166718	6382132	14824152	2372779	75029094	1273
2	Garba	810	50%	3578224	2264572	21785699	136141615	56045681	5229600	3106294	3956366	2233282	47658495	57094753	18453586	357548166	6424
			75%	12693	153568	9402185	73651270	28009531	1955958	570917	50683	369977	14163087	32897434	5265620	166502922	2825
3	Chafa Balal	13580	50%	59990467	37966522	365246651	2282472998	939630058	87676508	52078354	66330190	37441933	799015259	957218210	309382350	5994449500	107698
			75%	212800	2574633	157631699	1234795360	469591891	32792478	9571670	849722	6202828	237450269	551539694	88280386	2791493430	47363
4	Ariya	355	50%	1568234	992497	9548053	59667004	24563231	2291985	1361400	1733963	978784	20887365	25023009	8087683	156703209	2815
			75%	5563	67304	4120711	32279260	12275782	857241	250217	22213	162151	6207279	14418011	2307772	72973503	1238
5	Kargi	420	50%	1855375	1174222	11296288	70591948	29060723	2711645	1610671	2051449	1157998	24711812	29604687	9568526	185395345	815
			75%	6581	79628	4875207	38189547	14523461	1014200	296031	26280	191840	7343823	17057929	2730321	86334848	305

4.7 Cost Estimate

The cost of any structure depends on its quantity and unit rates. The quantities of the proposed structures are quantified using the parameters measured during the field visit. The unit costs however have been estimated using the experience of Ethiopia as reference. Hence rough cost estimate of each site is presented in table 11. Summary of rough cost estimate of the Loglogo site is presented for reference in table 10.

Table 10 Sample rough cost estimate for Loglogo

S.no	Description	Unit	QTY	Rate (KSH)	Amount
1	**weir wall + Apron + Cutoffs + Undersluices**				
1.1	Excavation on loose to medium soil	cubic m	446.40	578.65	258,309.36
1.2	Backfilling and Compaction	cubic m	186.00	1,456.30	270,871.80
1.3	Masonry work	cubic m	310.00	10,000.00	3,100,000.00
1.4	Plastering work	square m	407.08	1,000.00	407,082.04
1.5	Site clearance	square m	3200	150.00	480,000.00
1.6	Concrete	cubic m	10	25000	250,000.00
2	**Wing walls**			-	
2.1	Excavation	cubic m	737.45	578.65	426,725.44
2.2	Backfilling and Compaction	cubic m	457.52	1,456.30	666,286.38
2.3	Masonry work	cubic m	457.52	5,854.35	2,678,482.21
2.4	Plastering work	square m	28.00	494.50	13,846.00
3	**Head regulator**			-	
3.1	Excavation	cubic m	51.45	578.65	29,771.54
3.2	Backfilling and Compaction	cubic m	31.92	1,456.30	46,485.10
3.3	Masonry	cubic m	31.92	5,854.35	186,870.85
3.4	Plastering	square m	2.40	494.50	1,186.80
3.5	Concrete pipe 0.6 m diameter	number	7.00	9,000.00	63,000.00
4	**Materials**				
4.1	Steel plate (for under sluice)				-
	(1.0m X1.0m X 3mm)	Pcs	7	25,000.00	175,000.00
4.2	Steel plate (for head reg. gates)				-
	(0.8m X 0.6m X 3mm)	Pcs	1	5,000.00	5,000.00
4.3	Angle iron				-
	40mm X 40mm X 6m for gate reinforcement and grooves	Pcs	15	3,500.00	52,500.00
4.4	10mm diam R. bar	Pcs	4	750.00	3,000.00
4.5	Rubber seal	m	50	2,500.00	125,000.00
5	**Infrastructure**			-	
5.1	Excavation on loose to medium soil	cubic m	3,200.00	578.65	1,851,680.00
5.2	Backfilling and Compaction	cubic m	500.00	1,456.30	728,150.00
5.3	Masonry work	cubic m	300.00	5,854.35	1,756,305.00
5.4	Plastering work	square m	28.00	494.50	13,846.00
6	***Total investment Cost***				**13,589,398.52**
7	***Operation and maintenance cost+Contigency (20%)***				**2,717,879.70**
8	***Total Project Cost***				**16,307,278.22**

Table 11 Cost summary of all sites

S.no	Sites	Estimated Cost (KSH)
1	Loglogo	16,307,278
2	Garba	16,074,751
3	ChafaBalal	18,062,737
4	Ariya	6,045,406
5	Kargi	39,955,235

The cost summary is also plotted in figure 15 below.

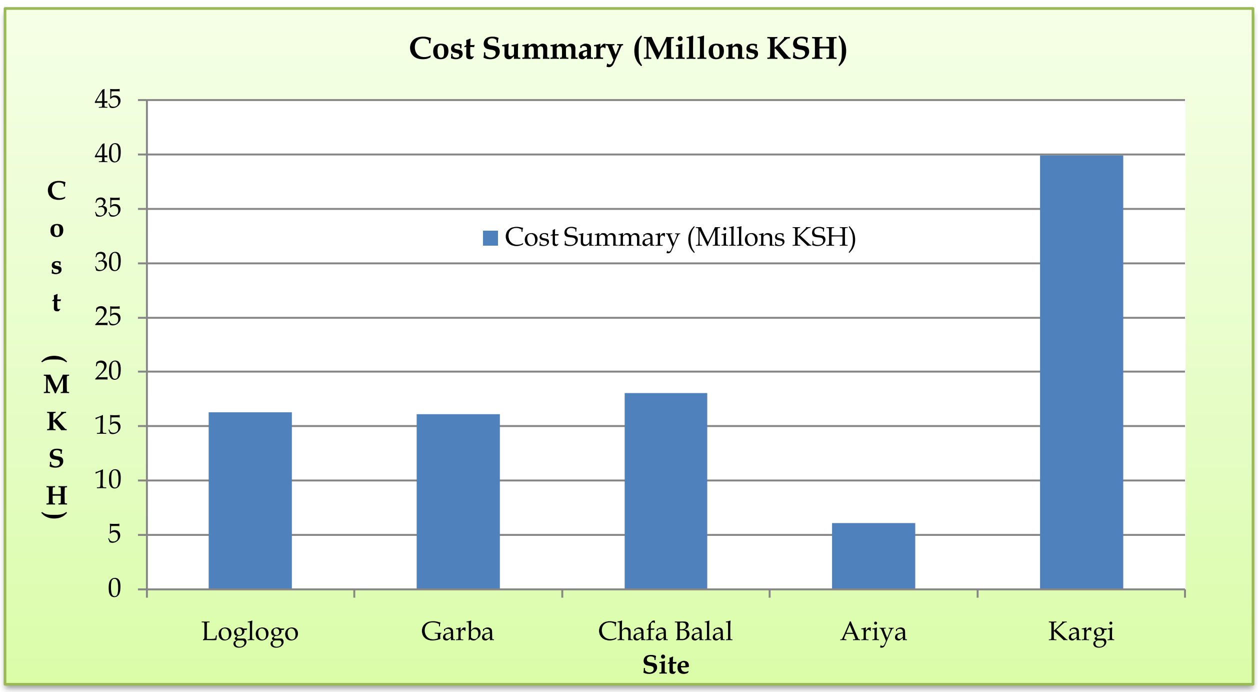

Figure 15 Summary of the rough cost estimate

5. EVALUATION

The purpose of this study is to identify bright spots that can be scaled up to other parts of the County. It is therefore, wise to choose sites that can be exemplary both technically and economic feasibility. As a result, the sites will be compared based on the information gathered during the field visit and further desk work analysis undertaken. Hence, the information below is presented in a summarized way to undertake the comparisons. The comparisons basically depend on:

- The capacity of the flood water to irrigate the available land
- The unit investment cost per hectare of irrigated land and
- Technical observations during the field work

5.1 The Capacity of the Flood Water to irrigate the Available Land

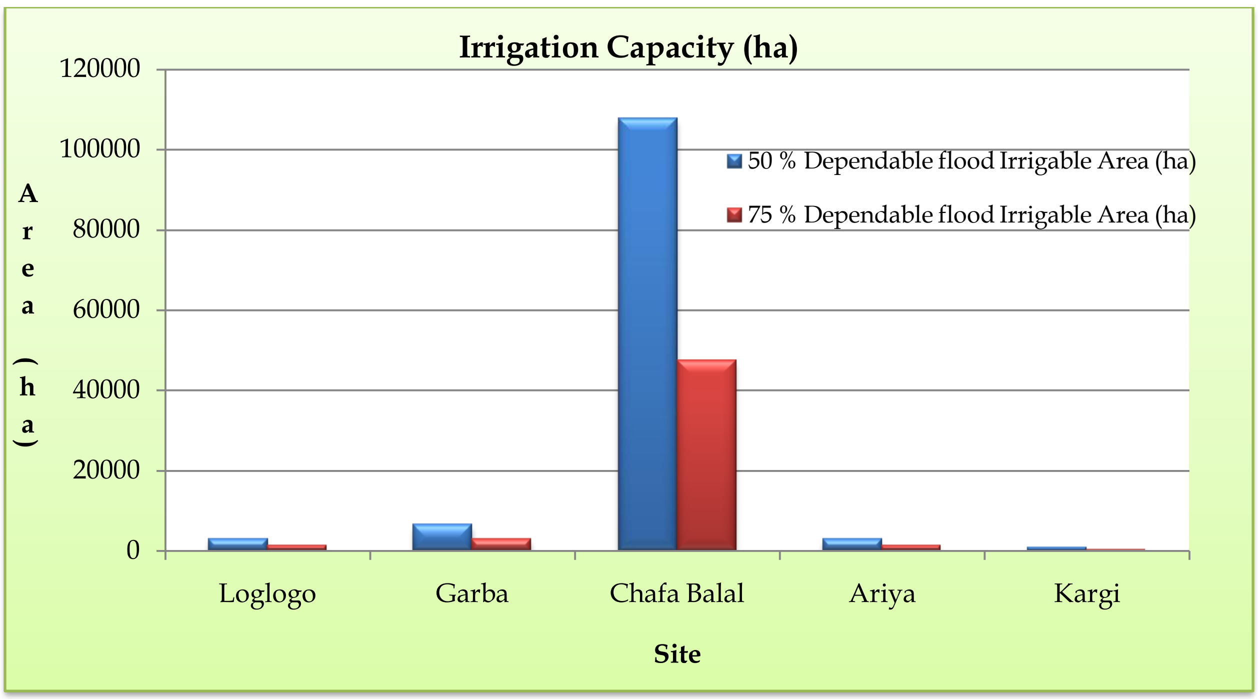

Figure 16 Irrigable area for both 50% and 75% dependable rainfalls for the sites in Marsabit County

Figure 16 shows that, the potential irrigable areas under both scenarios i.e using 50 % and 75 % dependable rainfall. The figure indicates that, for the 75% dependable rainfall, for a rain that occurs in three years out of four years, there is an irrigable area where ChafaBalal, Garba, Loglogo, Ariya and Kargi are irrigating 47363 ha, 2825 ha, 1273 ha, 1238 ha and 305 ha of land respectively, with probability of success of 75%.It also shows that it is possible to irrigate areas in the County with a success probability of 50 %. This means that there is a 50 % chance to harvest or not harvest where ChafaBalal, Garba, Loglogo, Ariya and Kargi are irrigating 107698 ha, 6424 ha, 2895 ha, 2815 ha and 815 ha of land respectively.

5.2 Unit Investment Cost per Hectare of Irrigated Land

Unit investment cost (cost per hectare) is among one of the project viability indicators. In this analysis, even though the cost estimate is rough, it has been used as one of relative viability indicators.

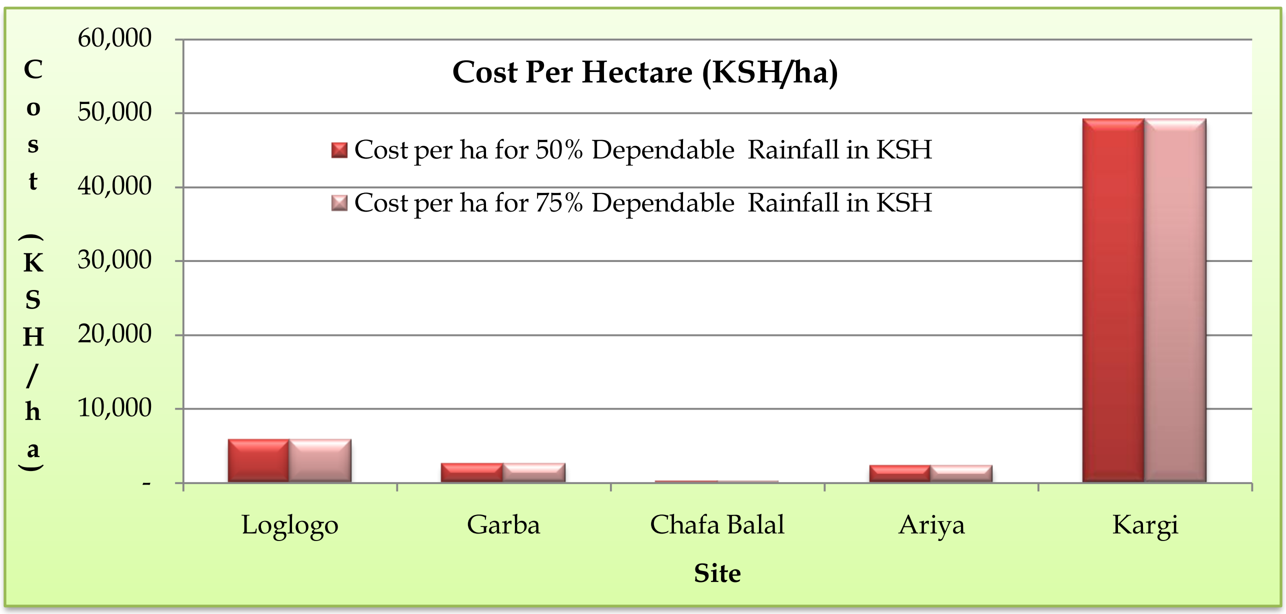

Figure 17 Cost per hectare in Kenyan Shilling for the sites identified in Marsabit

Figure 17 shows the cost per ha for all sites identified during the field work. The figure indicates that the cost per ha of irrigable land for ChafaBalal, Ariya, Garba, Loglogo and Kargi are 167, 2147, 2502, 5634 and 49039 KSH respectively. ChafaBalal is the least expensive and Kargi is the most expensive. However, it is good to note that the nature of the schemes is different. The system in ChafaBalal is a direct utilization of the flood but the system in Kargi is the utilization of flood after storing in a dam. It is clear that the Kargi scheme is going to be more expensive but more reliable system.

5.3 Observations during the Fieldwork

The observation during field visits is also considered one of the technical viability indicators. By technical viability, it is to mean that, the suitability of the site for the intended implementation in terms of:

- Foundation strength and bearing capacity
- Abutment strength and workability
- Availability of suitable off-take location
- Availability of construction materials in the vicinity and
- Command area suitability and availability

In addition, from the observations during the field work, it is noticed that the river bed in ChafaBalal is with reverse gradient, which creates/leads to small ponds/storage in the river course. Therefore, the figure indicated as cost per ha for the scheme seems undermined because of the advantage of big Watershed (more flood), which in reality seems to contribute less flood due to abstraction from the upstream side. Moreover, the proposed structure does not have a capacity to irrigate the overall estimated area using a single diversion point. Therefore, careful analysis should be in place while selecting the best site. The figures relatively indicate the potential irrigable land in the sites with relative cost.

Therefore, based on the above analysis, ChafaBalal, Ariya, and Garba seem more feasible than others and could be implemented for introducing the technology. Particularly, investing in Ariya seems more attractive because (there will be) no need of constructing the headwork, which is usually the major part of the investment. As the site is located in a highway road connecting Addis and Nairobi, the investment needed is basically associated with infrastructure development only. Hence it is recommended to implement Ariya as a pilot project as the site is where others can learn from.

6. CAPACITY BUILDING NEEDS

The Consultants have employed their experience in the field of flood-based farming to evaluate the capacity building gaps of the Country during their various interactions with the experts and the agro-(pastoralists). The interactions include the introductory presentations, discussions during travels on the road and deliberations during field investigations.

If not the only, flood-based farming systems (FBFS) is one of the top potentials of the County.

- The County is endowed with potential FBFS including seasonal streams, culverts and small dams;
- The County owns fertile and flat potential land for flood based farming systems crop and crop/forage production;
- The County government, GIZ and the experts are committed to see the realization of the flood based farming systems potential;
- The agro-(pastoralist) communities are motivated and committed to this new initiative of flood based farming systems development.

However, Marsabit County seems to lag behind Turkana County in this aspect. Unlike Turkana County, the understanding of FBFS in Marsabit was found to be limited to recession farming and community pond construction at the beginning of the reconnaissance mission. Spate irrigation from Lagas (Seasonal streams), which is high potential, was not given much thought initially by the experts, decision makers and communities. This challenge was, however, overcome immediately after a brief discussion between the experts and decision makers of the County and the Consultants on what FBFS is. It can generally be concluded that FBFS is at its early stage in the Marsabit County. As a result, practical oriented training and subsequent coaching is required during the initial stage of the FBFS development. Practical training becomes even more critical since the design, construction and management of flood-based farming systems is very challenging as it differs substantially from conventional irrigation. The agro-pastoralists have also clearly expressed their interest to this new initiative. However, they have also recommended the need for parallel capacity building and proper extension services.

As an entry point to bridge this critical capacity gap, 3 relevant experts from the County have participated in the regional short course on **"Integrated Watershed Management and Flood-based Farming Systems In ASAL Areas, Horn of Africa"** held at Mekelle University, Ethiopia, during 13 – 27 October 2014. These trainees will serve as "Change agents" in the development and management of flood based farming systems of the County. However, in addition to flood based farming systems, the Tigray national Regional State (Northern Ethiopia) is also a pioneer in earthen dam and perennial river diversion irrigation developments (Figure 18). More than 150 dams and 200 river diversion irrigation schemes have been constructed in Tigray during the last 20 years and hugely benefited the rural farming communities in substantially improving their livelihood. Accordingly, extra field visit and experience sharing days were organized to the experts from the County to the other watershed management based water harvesting and irrigation systems in Tigray region. It is believed that this opportunity has made some improvements to the knowledge and skill of the few "change agents". However, this does not mean that they are fully capable of planning, designing, constructing and operating successful flood-based farming irrigations schemes due to the special nature of floods. Tigray was able to manage flood properly over 15 years of struggle that combines failures, researches and subsequent improvements to the designs and construction of flood based farming systems.

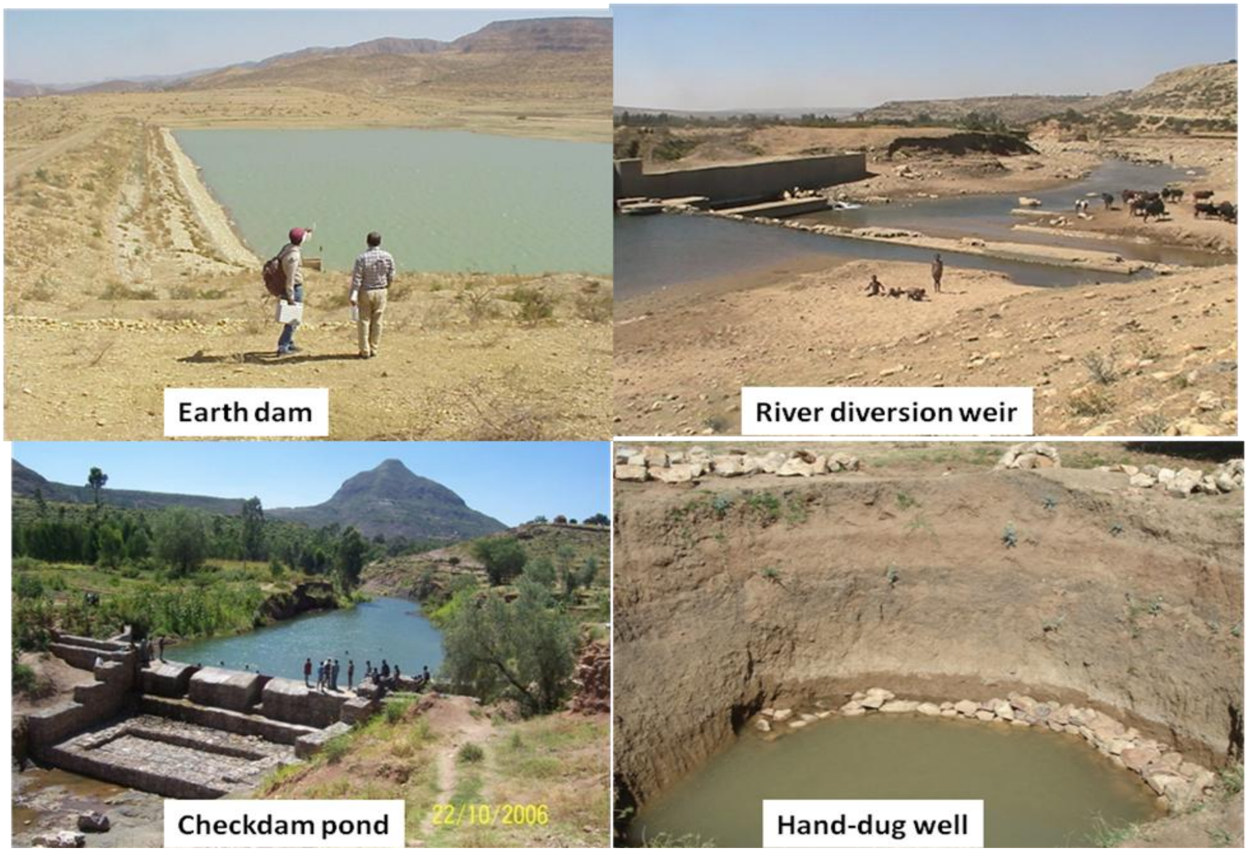

Figure 18 Some of the watershed management and water harvesting techniques in Tigray in addition to FBFS

Taking into account all the above facts and the observation and evaluation made during the reconnaissance mission, the Consultants recommend the following capacity building and experience sharing visits to be given top priority before and during the implementation of the planned flood based farming systems development initiative in the County:

- As indicated above, the "Change agents" are not ready to implement successful flood based farming systems right away. The Consultants, therefore, propose to serve as coaches to the "Change agents" during the design of the first 1 or 2 pilot spate irrigation systems in the County.
- In collaboration with the "Change agents", the Consultants propose delivery of short term training to relevant experts from the 4 sub-counties in Marsabit on the following topics, among others:
    - Hydrology and watershed management;

    - Design of headwork and infrastructure of different irrigation systems (Spate, dams, river diversions, etc);
    - Water management of different irrigation systems;
    - Operation and maintenance of irrigation schemes.
- Experience sharing visit of various stakeholders from the County to Tigray will be very essential in order to enhance the common understanding, vision and commitment to the initiative among the wider community:
    - Policy makers;
    - Experts;
    - Agro-(pastoralists).
- The capacity building of agro-(pastoralists) will be handled by the trained experts.

7. CONCLUSIONS

After analyzing the information and data collected from the County, we have come with the following concluding remarks:

- Flood based farming can be considered as an alternative for supporting the agricultural system in Marsabit County, where many poor segments of the County can be lifted out of poverty.
- Data scarcity such as the 24 hours point rainfall, GIS based administrative boundary data, land use data and unit costs of construction materials were the main challenges during analysis.
- The rainfall in Marsabit County is less reliable source of water to support the agricultural system (crop and forage farming).
- The 50 % dependable rainfall analysis indicates that, there is a possibility of irrigating ChafaBalal: 107698 ha, Garba: 6424 ha, Loglogo: 2895 ha, Ariya: 2815 ha and Kargi: 815 ha respectively.
- The 75 % dependable rainfall analysis indicates that, there is a possibility of irrigating ChafaBalal: 47363 ha, Garba: 2825 ha, Loglogo: 1273 ha, Ariya: 1238 ha and Kargi: 305 ha respectively.
- The construction of modern flood based farming structures in the County is promising for almost all the sites.
- From the overall evaluation, Ariya is the best site that can be considered for introducing flood based farming in the County mainly because of low cost associated with its headwork.

8. RECOMMENDATIONS

After drawing some concluding remarks and considering experiences from various field works in similar dryland areas, the following points are recommend:

- Community mobilization and local technical capacity development are crucial to introduce flood based farming as new technology in the County.
- Data base systems on the 24 hours point rainfall, GIS based administrative boundary data, land use data and unit costs of construction materials within the County Ministry of Agriculture, Livestock & Fisheries has to be improved.
- Further detailed study and design is recommended to choose the best site among the five sites visited.
- To ensure the sustainability of flood based farming practices, it is best advised to implement and learn from one best site and then expand it further in to various areas. As the practice is new to Marsabit the challenges will be there that need frequent supervision and amendments. Hence, to address the required solutions timely and appropriately it is better to deal with one site rather than with several projects. It is learnt that, this is a practice in most developing countries, where several technologies fail or have been rejected by agro-pastoralists mainly because of the way the technologies are introduced.
- It is good to explore other sources like groundwater which supplement one another with the flood base farming systems.
- The Consultants propose delivery of short term training to relevant experts from the 4 sub-counties in Marsabit.
- Experience sharing visit of various stakeholders composed of policy makers, experts and agro-pastoralists from the County to Tigray will be very essential in order to enhance the common understanding, vision and commitment to the initiative.

9. REFERENCES

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APPENDIX

Curve Number

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment*	Hydrologic condition**	A	B	C	D
Fallow	Bare Soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Dependable Rainfall Analysis of Marsabit Meteorological Station

Year	January	February	March	April	May	June	July	August	September	October	November	December	Rank	January	February	March	April	May	June	July	August	September	October	November	December	Probability of
	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	(m)	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Occurrence P=m/(N+1)
1980	0	2.5	3.5	102.1	137.6	0	10.7	28.9	2	10.8	44.9	2.5	1	276.8	133	203.4	565.5	364.9	68.5	35.8	28.9	49.3	429.7	472.6	310.8	0.0323
1981	1.5	0.4	203.4	537.1	104.4	7	5.7	8.5	0.8	197.3	41.7	34.9	2	104.4	76.4	120.4	537.1	298	37.2	26.6	28.2	20.7	342	288.8	157.7	0.0645
1982	2.6	0.2	12.8	565.5	286.2	8.3	6.7	4.2	0.9	342	129.5	110.6	3	77.4	51.2	110.1	511.7	286.2	31.9	25.8	27	13.6	209.1	219.5	148.5	0.0968
1983	4.3	22.7	0.6	336.6	51.4	4	35.8	10.5	20.7	15.8	32.6	30.9	4	56.8	46.7	109.9	382.9	248.4	19.3	24.7	20.2	11.8	197.3	201.7	144.7	0.1290
1984	0	0	2.2	180	16.1	1.3	5.6	0.6	13.6	109.7	199.5	16.4	5	53.2	40.8	108.9	370.7	243.5	16.8	15.3	18.9	7.5	194.6	199.5	139.7	0.1613
1985	19.3	51.2	99.2	344.7	364.9	19.3	3.4	9.4	3.5	111.9	69.1	54.9	6	46.6	38.8	99.2	347.1	191.1	14.9	14.2	17.4	6.8	181	193.2	110.6	0.1935
1986	0	0	72.7	224.9	11.8	8	6.3	0	0.7	33.5	125	34.8	7	45.1	23	72.7	344.7	137.6	13.4	13	16.3	5.8	121.3	185.3	87.6	0.2258
1987	45.1	0	11.4	169.3	298	37.2	15.3	16.3	4.2	1.7	73.4	15.1	8	41.1	22.7	69.9	336.6	120.9	12.8	12.4	13.2	5	111.9	140.2	84.7	0.2581
1988	31.8	3.4	59.9	511.7	14.6	10.8	5.4	9.2	49.3	121.3	140.2	58.1	9	32.9	19	61.1	313.8	111.2	11.7	10.7	12.2	4.9	110.7	138	75.7	0.2903
1989	56.8	38.8	32.3	299.5	76.8	11.7	3.2	3.6	0.3	55.2	201.7	38.2	10	31.8	13.8	59.9	302.4	104.4	10.8	7.4	10.6	4.2	109.7	129.5	70.3	0.3226
1990	53.2	133	61.1	302.4	23.3	13.4	0.2	0.3	1	21	109.5	148.5	11	19.3	7.2	46.3	299.5	76.8	9.2	7.2	10.5	3.7	108.6	125	58.1	0.3548
1991	46.6	0.6	109.9	68.2	15.6	3.9	25.8	20.2	3.7	0.2	27.5	87.6	12	18.6	3.4	42.8	263.1	76.6	8.3	6.7	9.6	3.5	99.7	109.5	54.9	0.3871
1992	0.5	46.7	0	146.2	23	1.5	12.4	3.7	0.7	57	89.6	157.7	13	10.9	3.3	42.5	254.9	72.1	8.2	6.3	9.4	3.2	79.3	109.2	45.6	0.4194
1993	104.4	0	10.5	240.5	243.5	16.8	5.4	1.1	1.2	74.3	59.3	11.3	14	8.1	3.2	32.3	240.5	71.7	8	5.7	9.2	2.8	74.3	92.1	38.2	0.4516
1994	0	0	8.2	111.7	72.1	0.8	26.6	10.6	2.8	209.1	0.5	70.3	15	8.1	3	26.8	224.9	64	7	5.6	8.5	2	57	89.6	34.9	0.4839
1995	0	76.4	42.8	370.7	120.9	1.4	4.4	18.9	0.8	47.1	138	32.5	16	8	2.5	24.8	181.3	53.1	6.1	5.4	8.5	1.9	55.2	83	34.8	0.5161
1996	8.1	3	46.3	81.4	27	68.5	7.2	3.6	5.8	0.8	68.3	0.1	17	4.3	0.8	21.8	180	51.4	5.6	5.4	4.2	1.5	54.6	73.4	32.5	0.5484
1997	0	0	42.5	347.1	1.7	3.4	2.2	0	4.9	429.7	472.6	139.7	18	2.6	0.6	17.6	176.6	27	4.7	5	3.7	1.2	47.1	69.1	32.1	0.5806
1998	276.8	40.8	110.1	105.6	191.1	31.9	14.2	3.6	0	0.8	109.2	9.1	19	2.5	0.4	15.1	169.3	23.3	4	4.4	3.6	1.1	36.1	68.3	30.9	0.6129
1999	1.2	0	26.8	143.6	9.3	5.6	5	8.5	1.5	10.9	92.1	32.1	20	1.5	0.2	12.8	157.7	23	3.9	3.4	3.6	1	33.5	59.3	17.6	0.6452
2000	8	0.1	0.8	11.4	1	9.2	1.3	0	7.5	8.3	39.5	12.5	21	1.2	0.1	11.4	146.2	16.1	3.4	3.2	3.6	0.9	23.2	44.9	16.4	0.6774
2001	32.9	3.3	69.9	181.3	10.7	8.2	7.4	27	0	23.2	193.2	45.6	22	1	0	10.5	143.6	15.6	1.8	2.6	2.9	0.8	21	42.1	15.1	0.7097
2002	18.6	3.2	120.4	254.9	53.1	6.1	13	13.2	5	54.6	42.1	310.8	23	0.5	0	8.2	111.7	14.6	1.7	2.2	1.6	0.8	15.8	41.7	12.5	0.7419
2003	0	0	17.6	263.1	64	12.8	0	17.4	6.8	36.1	219.5	75.7	24	0	0	6.5	105.6	11.8	1.5	2	1.1	0.7	10.9	39.5	11.3	0.7742
2004	41.1	13.8	108.9	313.8	111.2	1.7	1.3	1.6	1.1	79.3	185.3	17.6	25	0	0	3.5	102.1	10.7	1.4	1.8	0.6	0.7	10.8	34.8	9.1	0.8065
2005	1	0.8	0.2	176.6	248.4	14.9	2	2.9	0.5	110.7	19.5	1.5	26	0	0	2.2	101.5	9.5	1.3	1.3	0.3	0.5	8.3	32.6	6.7	0.8387
2006	2.5	23	24.8	382.9	71.7	0	1.8	9.6	1.9	181	0	144.7	27	0	0	0.8	81.4	9.3	0.8	1.3	0	0.3	1.7	27.5	2.9	0.8710
2007	8.1	7.2	15.1	101.5	76.6	0	24.7	28.2	11.8	108.6	83	6.7	28	0	0	0.6	68.2	6.9	0	0.2	0	0	0.8	19.5	2.5	0.9032
2008	77.4	0	21.8	157.7	6.9	1.8	2.6	12.2	3.2	99.7	288.8	2.9	29	0	0	0.2	26	1.7	0	0	0	0	0.8	0.5	1.5	0.9355
2009	10.9	19	6.5	26	9.5	4.7	0	0	0	194.6	34.8	84.7	30	0	0	0	11.4	1	0	0	0	0	0.2	0	0.1	0.9677

Dependable Rainfall Analysis of Moyale Meteorological Station

Year	January	February	March	April	May	June	July	August	September	October	November	December	Rank	January	February	March	April	May	June	July	August	September	October	November	December	Probability of
	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	RF(mm)	(m)	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Decending	Occurrence P=m/(N+1)
1980	1.2	2.3	35.7	54.8	203.9	1.4	12.2	53.1	26.2	30.3	0	0	1	115.9	84.3	182.4	360.7	470.2	56.3	59.8	53.1	118.1	605.4	277.1	107	0.0323
1981	0	5.6	182.4	343.4	65.1	20.9	6.9	14.6	12	76.8	78.3	8.9	2	68.6	67.9	150.3	343.4	282.2	50	23.9	35.3	84.6	475.9	219.2	94.2	0.0645
1982	2	4.5	22.7	238.2	470.2	14.5	13.6	1.7	118.1	213.1	75.8	20.9	3	42	47.6	140.9	304.9	273	43.2	21.9	32.4	61.1	213.1	168	79.7	0.0968
1983	23.7	26.8	2.4	214.8	178	41.6	20.7	0.4	17.2	20.1	36.1	18.9	4	37.8	47.5	121	287.1	205.4	41.6	20.7	21.9	50.2	185.6	152.2	66.2	0.1290
1984	0.9	0.2	14.9	52.1	98.3	6.3	10.2	0.4	5.3	59.3	96.5	27.5	5	37.5	35.7	103.3	258.7	203.9	37.3	18.2	21.1	43.5	152.7	140.6	59	0.1613
1985	37.8	27.7	150.3	166.2	282.2	27.9	9.1	12.1	9.4	152.7	19.9	4.8	6	30.9	32.4	87.1	238.4	184.3	33.9	16.5	20.4	26.2	152.2	140	51.9	0.1935
1986	0	17.6	14.6	287.1	60.7	22.8	16.5	1	7.7	63.3	140.6	51.9	7	23.7	27.7	71.1	238.2	178	27.9	13.6	20.2	20.6	149.4	125.1	51.1	0.2258
1987	18.1	10.1	51.4	137.9	273	4.6	5.2	32.4	9.3	12.1	50.2	4.7	8	23.2	26.8	62.9	232.7	156.6	23.5	13.5	20	20.1	136.6	96.5	43.8	0.2581
1988	8.6	32.4	33.9	360.7	19.5	50	0	20.2	84.6	41.3	67.6	43.8	9	19.4	25.9	58.4	226.1	148.3	22.8	12.2	16.8	18.2	122.3	95	30.2	0.2903
1989	19.4	47.6	44.6	213.3	156.6	33.9	5.1	5.7	6.8	58.2	125.1	94.2	10	18.1	24.5	51.4	214.8	121.5	21.7	11.9	14.6	17.2	96.3	92	29.4	0.3226
1990	12.1	84.3	41.4	226.1	71.2	12.6	3.2	0.4	2.7	96.3	50.2	79.7	11	16.7	21.8	51.3	213.3	117.5	21.3	11.4	13.9	12.3	92.1	91.2	27.9	0.3548
1991	30.9	47.5	58.4	71.8	184.3	15.5	59.8	20	0	29	26.3	13.3	12	15.9	19.1	44.6	196.9	116.6	20.9	10.3	12.4	12.1	88.5	88.6	27.5	0.3871
1992	2.2	14.1	24.3	94.7	116.6	10.2	23.9	6.3	50.2	43.2	168	59	13	12.1	17.6	41.7	179.4	98.3	17.7	10.2	12.1	12	78.4	78.3	25.5	0.4194
1993	42	24.5	38.2	67.2	205.4	37.3	9.8	0	1.4	73.4	50.5	6.3	14	11.4	14.1	41.4	176.9	98.3	15.5	9.8	9.8	11.3	76.8	75.8	23.4	0.4516
1994	0	0	38	78.3	98.3	17.7	9.8	1.5	20.1	136.6	219.2	25.5	15	8.6	10.1	39.3	166.2	96.3	15.2	9.8	9.2	10.6	73.4	69	20.9	0.4839
1995	0	35.7	121	99.2	46.9	10.1	21.9	20.4	4.6	88.5	44.9	18.5	16	8.3	5.6	38.2	137.9	90.2	14.5	9.1	6.3	9.4	72.5	67.6	20.2	0.5161
1996	8.3	0.1	103.3	108.9	121.5	10.8	13.5	0.3	7.6	20.3	59.9	11.8	17	6.2	4.5	38	129.8	84.9	12.6	8	5.7	9.3	63.3	59.9	18.9	0.5484
1997	0	0	41.7	304.9	21.8	21.3	7.5	3	11.3	605.4	277.1	51.1	18	5.8	3.8	35.7	108.9	83.4	12.6	7.5	3	7.9	59.3	59.3	18.5	0.5806
1998	115.9	67.9	16.1	238.4	148.3	56.3	18.2	21.1	1.5	9.9	59.3	23.4	19	5.3	2.6	33.9	106.6	82.1	10.9	6.9	2.5	7.7	58.2	57.2	16.5	0.6129
1999	0.6	1.5	71.1	81.3	66.5	23.5	8	12.4	0.7	92.1	69	29.4	20	2.2	2.3	33.8	99.2	71.2	10.8	6.8	2.2	7.6	43.2	53.6	13.3	0.6452
2000	15.9	0	0	70.9	82.1	5	11.9	21.9	20.6	72.5	53.6	27.9	21	2	1.5	33.6	94.7	67.9	10.2	5.2	1.7	6.8	41.3	53.1	12.2	0.6774
2001	16.7	21.8	140.9	179.4	18.3	9.3	6.8	16.8	12.1	20	91.2	16.5	22	1.2	1.1	26.9	93.3	66.5	10.1	5.1	1.7	5.3	30.3	50.5	11.8	0.7097
2002	5.8	0	62.9	196.9	83.4	15.2	3	2.5	43.5	149.4	27.3	107	23	0.9	0.2	24.3	81.3	65.1	9.9	4.2	1.5	4.6	29	50.2	8.9	0.7419
2003	23.2	3.8	39.3	0.8	96.3	12.6	2.7	13.9	12.3	8.6	140	20.2	24	0.8	0.1	22.7	78.3	60.7	9.3	3.9	1	3.4	23.9	50.2	6.3	0.7742
2004	37.5	25.9	26.9	258.7	24.4	9.9	3.9	0.5	7.9	152.2	92	12.2	25	0.6	0	16.1	71.8	60.1	6.3	3.7	0.5	2.7	20.3	44.9	4.8	0.8065
2005	11.4	0	10.5	93.3	117.5	21.7	10.3	2.2	3.4	23.9	57.2	0	26	0	0	14.9	70.9	46.9	5	3.2	0.4	1.5	20.1	36.1	4.7	0.8387
2006	0.8	2.6	51.3	232.7	60.1	2.1	3.7	9.2	61.1	475.9	152.2	66.2	27	0	0	14.6	67.2	24.4	4.6	3	0.4	1.4	20	27.3	3.4	0.8710
2007	5.3	19.1	33.8	129.8	90.2	0	4.2	35.3	18.2	122.3	88.6	0.6	28	0	0	10.5	54.8	21.8	2.1	2.7	0.4	0.7	12.1	26.3	0.6	0.9032
2008	6.2	0	87.1	176.9	67.9	43.2	11.4	9.8	10.6	185.6	53.1	3.4	29	0	0	2.4	52.1	19.5	1.4	0	0.3	0.7	9.9	19.9	0	0.9355
2009	68.6	1.1	33.6	106.6	84.9	10.9	0	1.7	0.7	78.4	95	30.2	30	0	0	0	0.8	18.3	0	0	0	0	8.6	0	0	0.9677

Rainfall data of Marsabit Meteorological Station

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
1935	0	42.4	3.7	269.6	205.6	4.9	11.7	40.2	46	16.8	133.4	123.4	897.7
1936	67.1	68.9	44.3	267.7	194.9	0	6.9	5.3	13.5	133.2	52.4	103.5	957.7
1937	34.2	1.3	149.9	105.9	127.8	14.5	0	6.3	6.6	240.5	229.3	45.5	961.8
1938	13.9	14.5	5.6	89.3	35.1	7.6		12.5	1.8	245.3	31.6	99.8	557
1939	3	10.7	35.2	262.4	31	0	2	0	0	210	113.3	20.3	687.9
1940	2.1	71.4	284.4	371.3	20.6	1.8	21.8	33.3	1.3	116.8	47	0	971.8
1941	0	5.1	187.8	495.7	70.3	27	0	10.2	1.3	289.2	144	122.4	1353
1942	3.6	1.5	128.1	248.9	116.4	14.5	6.1	12.3	0	29.5	222.8	0	783.7
1943	0	97	37.6	167.4	254	11.9	0	0	0	0	0	162	729.9
1944	173	0	47.8	293.5	111.9	2	58.4	29	28.2	140.1	118	116.3	1118.2
1945	0.5	0	27.9	42.5	57.9	33.4	6.6	12.2	30.7	39.6	130		381.3
1946	8.2	0.8	7.7	378	66	0	16.7	47	66.1	111.8	64.1	10.2	776.6
1947	40.4	4.1	199.2	323.5	25.1	18.5	4.3	22.8	18.8	26.5	199.6	100.5	983.3
1948	0.3	0	41.8	385.7	0	3.8	1.6	9.8	1.5	127.9	166.3	86.3	825
1949	4.6	0	410.3	67.9	88.7	4.1	25.6	25.2	14.5	20.3	85.1	25.9	772.2
1950	5.1	4	94.6	319.1	130.9	5.8	27.1	4.4	7.7	2.8	53.1	8	662.6
1951	0	0	59	233.3	161.2	9.6	18	0	19.8	221.7	193.8	96.7	1013.1
1952	0.3	0	14.8	154.7	158.8	5.6	1	7.9	43.7	114	198.7	65.7	765.2
1953	185.5	7.7	15.4	98.5	261.1	0	4.1	87.4	1.3	332.3	131	48.3	1172.6
1954	0	0.5	14	235	204.2	2.3	14	43.1	0	10.4	243.2	6.5	773.2
1955	34	0	21.1	206.9	33.6	7.8	7.6	1.8	0	47.5	122.9	0	483.2
1959			66.8	315.9		2.8	27.1	0	3	133.1	90.9	28.4	668
1960		0	253.8	77	34.5	43.8	16.8	3.3		146.2	37.3	62.2	674.9
1961	53.4	5.1	27.1	227.5	267	0	39.9	183.4	41.1	261.8	623.1	87.4	1816.8
1962	0	0	92.5	165.6	170.1	0	7.4	19.3	0	79.5	68.7	29.4	632.5
1963	24.4	9.7	69.8	551.3	15.3	1.8	28.5	34.6	45.7	3.6	240.3	209.9	1234.9
1964	134.4	141	80.9	142.8	0	0	25.4	7.3	0	93.7	29.2	209.6	864.3
1965	29.4	0	23.4	244.4	2.3	6.1	2.3	0	1.3	186.2	315.8	6.8	818
1966	0	34.6	168.5	308.6	3	0	3.3	12	5.3	163.5	68.5	7.9	775.2
1967	0	0	43.4	209.2	228.1	0	8.1	0	10.2			0	499
1968	0					0	0	0	0				0
1969	139.8	222.2	119.2	80.6	173.9	3.9	5	40.4	0.5	77.8	153	29.7	1046
1970	134.9	1	54.1	685.4	8.6	1.8	5.6	7.2	0	41.9	32.8	6.3	979.6
1971	0	0	37.6	118.4	114	5.6	0	0	0	158.3	153.2	26.6	613.7
1972	23.9	3.6	5.3	186.3	70.5	2.8	5.1	0	13.5	216.8	101.3	10.4	639.5
1973	1.5	1.3	1	84.7	0	0	0	30.5					119
1974							20.4				51.8	44.1	116.3
1975	55.2	0	35.9	208.1	54.5	18.4	48.8	0.7	12.2	1.3	65.3	0	500.4
1976		8.7	0.5	112.1	31.5	0.4	2.7	7.2	5.8	31	84.8		284.7
1977	29.1	1.7	43.1	266.6	84.6	2.8	1.6	5.7	13.2	132.1	243.8	22.8	847.1
1978	49.6	214.3	291.6	134.6	3.5	4.7	15.4	1.6	10.2	148.8	78.1	57.5	1009.9
1979	312.4	73.1	132.8	188.3	24.7	57.9	18.3	13.8	11.4	99.2	71.4	111.9	1115.2
1980		2.5	3.5	102.1	137.6	0	10.7	28.9	2	10.8	44.9	2.5	345.5
1981	1.5	0.4	203.4	537.1	104.4	7	5.7	8.5	0.8	197.3	41.7	34.9	1142.7
1982	2.6	0.2	12.8	565.5	286.2	8.3	6.7	4.2	0.9	342	129.5	110.6	1469.5
1983	4.3	22.7	0.6	336.6	51.4	4	35.8	10.5	20.7	15.8	32.6	30.9	565.9
1984	0	0	2.2	180	16.1	1.3	5.6	0.6	13.6	109.7	199.5	16.4	545
1985	19.3	51.2	99.2	344.7	364.9	19.3	3.4	9.4	3.5	111.9	69.1	54.9	1150.8
1986	0	0	72.7	224.9	11.8	8	6.3	0	0.7	33.5	125	34.8	517.7
1987	45.1	0	11.4	169.3	298	37.2	15.3	16.3	4.2	1.7	73.4	15.1	687
1988	31.8	3.4	59.9	511.7	14.6	10.8	5.4	9.2	49.3	121.3	140.2	58.1	1015.7
1989	56.8	38.8	32.3	299.5	76.8	11.7	3.2	3.6	0.3	55.2	201.7	38.2	818.1
1990	53.2	133	61.1	302.4	23.3	13.4	0.2	0.3	1	21	109.5	148.5	866.9
1991	46.6	0.6	109.9	68.2	15.6	3.9	25.8	20.2	3.7	0.2	27.5	87.6	409.8
1992	0.5	46.7		146.2	23	1.5	12.4	3.7	0.7	57	89.6	157.7	539
1993	104.4		10.5	240.5	243.5	16.8	5.4	1.1	1.2	74.3	59.3	11.3	768.3
1994	0	0	8.2	111.7	72.1	0.8	26.6	10.6	2.8	209.1	0.5	70.3	512.7
1995	0	76.4	42.8	370.7	120.9	1.4	4.4	18.9	0.8	47.1	138	32.5	853.9
1996	8.1	3	46.3	81.4	27	68.5	7.2	3.6	5.8	0.8	68.3	0.1	320.1
1997	0	0	42.5	347.1	1.7	3.4	2.2	0	4.9	429.7	472.6	139.7	1443.8
1998	276.8	40.8	110.1	105.6	191.1	31.9	14.2	3.6	0	0.8	109.2	9.1	893.2
1999	1.2	0	26.8	143.6	9.3	5.6	5	8.5	1.5	10.9	92.1	32.1	336.6
2000	8	0.1	0.8	11.4	1	9.2	1.3	0	7.5	8.3	39.5	12.5	99.6
2001	32.9	3.3	69.9	181.3	10.7	8.2	7.4	27	0	23.2	193.2	45.6	602.7
2002	18.6	3.2	120.4	254.9	53.1	6.1	13	13.2	5	54.6	42.1	310.8	895
2003	0	0	17.6	263.1	64	12.8	0	17.4	6.8	36.1	219.5	75.7	713
2004	41.1	13.8	108.9	313.8	111.2	1.7	1.3	1.6	1.1	79.3	185.3	17.6	876.7
2005	1	0.8	0.2	176.6	248.4	14.9	2	2.9	0.5	110.7	19.5	1.5	579
2006	2.5	23	24.8	382.9	71.7	0	1.8	9.6	1.9	181	0	144.7	843.9
2007	8.1	7.2	15.1	101.5	76.6	0	24.7	28.2	11.8	108.6	83	6.7	471.5
2008	77.4	0	21.8	157.7	6.9	1.8	2.6	12.2	3.2	99.7	288.8	2.9	675
2009	10.9	19	6.5	26	9.5	4.7	0	0	0	194.6	34.8	84.7	390.7
	36.06716	22.59265	68.40145	234.0314	92.51594	9.043662	10.85634	14.80986	9.165217	105.8412	123.4609	58.53235	785.3181

Rainfall data of Moyale Meteorological Station

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
1935	0	45.1	17.6	59.6	272.2	3.1	2.4	28.5	81.8	90.2	65.8	31.8	698.1
1936	9.2	62.3	117	191.7	81	22.2	3.6	17.1	9.6	63.6	59.7	76.7	713.7
1937	25.6	44.3	67.1	278.2	171.5	11.2	0	7.1	23.9	170	131.9	0	930.8
1938	287.3	0	2.8	150	86.9	4.5	9.7	6.6	5.5	124.6	50.3	46.2	774.4
1939	9.9	15.5	36.7	155.9	396.4	14.2	0	0	0	0	0	0	628.6
1940	15.8	124.9	115.2	767.3	49.1	0	0	0	0	0	0	0	1072.3
1941	0	0	0	0	0	0	4.4	6.6	15	86.4	130.5	30.1	273
1942	0	3.5	68.3	184.1	141.7	0.5	7.7	1.3	0	33.6	30.3	16.1	487.1
1943	0.8	0	11.7	104.9	13.4	30.3	1	32.2	0	34.3	13	27.6	269.2
1944	55.4	2.8	45.1	149	89.8	6.1	15.1	26.9	31.8	106.9	160.5	25.2	714.6
1945	0	0	13.7	27.4	0	20.1	7.9	16.6	8.1	37.4	49.6	30.1	210.9
1946	3.3	0	62.8	191.5	28.7	7.4	6	29.6	95.3	38.4	32.6	0	495.6
1947	7.8	33.3	37.6	113.4	127.6	28.4	29	16.3	59.4	122.9	25.8	4.6	606.1
1948	0	39.9	112.3	142.3	64.4	10.1	23.1	5.1	3.3	140.7	122.6	43	706.8
1949	16.5	30.5	0	229.5	60.6	1.5	26.7	1.5	4.3	32	67.9	30.8	501.8
1950	7.7	10.7	69.6	174.8	266.3	8.1	15.7	18.8	8	22.4	32.6	0	634.7
1951	0	4.3	162.1	136.1	283.4	4.6	10.7	15.5	7.8	387.4	139.6	138.6	1290.1
1952	0	15.5	6.9	226.1	62.5	7.9	7.9	6.9	31	56.4	160.6	36.5	618.2
1953	8.6	38.2	52.9	303.5	127	1.5	9.6	38.7	5.1	224.1	74.7	9.9	893.8
1954	9.4	0	28.5	393.8	127.4	8.1		23.2	5	19.4	78.9	17.2	710.9
1955	20	0.3	22	95.4	47.2	27.4	15.8	6.9	0.8	67.2	59.4	24.8	387.2
1956	14.8	9.7	65.8	232.6	68	9.6	3.6	0	3.6	27.4	95.8	8.1	539
1959			20.1	395.2	44	40.6	36.1	10		115.1	51.2	15	727.3
1960	17.9	0	143.5	135.4		25	8.2	5.3	2.8	77.9	79.1	49.1	544.2
1961	3	4.3	39.4	142.3	110.3	18.9	26.4	94.3	73.5	250.2	266.9	69.6	1099.1
1962	3.3	2	95.4	156.4	111.2	8.7	17.5	18.6	7.4	116.5	79.5	63.2	679.7
1963	0.5	16.7	53.4	377.2	106.8	23	17.8	15.7	74.5	69.7	146.5		901.8
1964	15	9.4	34.8	192.2	131.6	24.1	15.4	24.6	9.7	71.8	34.8	160.9	724.3
1965	15.5	0	18.6	128.4	29.1	11	6.3	13.2	37.8	56.6	179.5	13.7	509.7
1966	10.2	99.6	76.2	154.9	65.1	7.2	19.1	21.9	18.3	201.6	57.6	10.2	741.9
1967	8.1	0	924.8	273.7	315.2	17.3	6.6	14.5	8.1	335.5	136.5	2	2042.3
1968	0	42.7	173.4	352.7	155.7	55.3	42.1	16	0	169.5	171.8	78.7	1257.9
1969	51.3	18.3	61.9	81.3	139.2	19.3	14.3	22.4	6.7	205.4	79.3	18.3	717.7
1970	176.4	22	118.4	186.7	121.8	6.8	31.9	14.9	8.9	110	19.1	0	816.9
1971	0	17.7	38	90.7	123.4	33.2	20.4	2.5	21.5	233	42.9	28.8	652.1
1972	0	38.9	3.5	60.7	192.5	11.9	7.8	15.1	39	151.4	142.2	34	697
1973	0	5	0	53.9	72.7	26.8	4.6	13.1	9.6	103.6	60	4.8	354.1
1974	11.1	0	146	136.2	135.9	25.7	6.8	0.4	2.4	35.8	27.5	13.1	540.9
1975	39.3	0	15.8	150.6	160	12.2	37.2	5.4	29.1	10.9	29.2	3.3	493
1976	3.7	14.9	19.6	111.7	163.4	5.5	5.3	6.3	48.4	121.1	77.4	16.9	594.2
1977	42.7	0.3	29.3	362.4	117.3		3.5	14.4	6.1	352.5	130.2	9.6	1068.3
1978	3.7	67.3	59.8	144.1	143	4.4	11.2	6.5	15.3	219.4	66.3	9	750
1979	89.7	27.2	37.4		143.2	7.5	60.6	15	7	95.2	84.5	79.9	647.2
1980	1.2	2.3	35.7	54.8	203.9	1.4	12.2	53.1	26.2	30.3			421.1
1981	0	5.6	182.4	343.4	65.1	20.9	6.9	14.6	12	76.8	78.3	8.9	814.9
1982	2	4.5	22.7	238.2	470.2	14.5	13.6	1.7	118.1	213.1	75.8	20.9	1195.3
1983	23.7	26.8	2.4	214.8	178	41.6	20.7	0.4	17.2	20.1	36.1	18.9	600.7
1984	0.9	0.2	14.9	52.1	98.3	6.3	10.2	0.4	5.3	59.3	96.5	27.5	371.9
1985	37.8	27.7	150.3	166.2	282.2	27.9	9.1	12.1	9.4	152.7	19.9	4.8	900.1
1986	0	17.6	14.6	287.1	60.7	22.8	16.5	1	7.7	63.3	140.6	51.9	683.8
1987	18.1	10.1	51.4	137.9	273	4.6	5.2	32.4	9.3	12.1	50.2	4.7	609
1988	8.6	32.4	33.9	360.7	19.5	50	0	20.2	84.6	41.3	67.6	43.8	762.6
1989	19.4	47.6	44.6	213.3	156.6	33.9	5.1	5.7	6.8	58.2	125.1	94.2	810.5
1990	12.1	84.3	41.4	226.1	71.2	12.6	3.2	0.4	2.7	96.3	50.2	79.7	680.2
1991	30.9	47.5	58.4	71.8	184.3	15.5	59.8	20	0	29	26.3	13.3	556.8
1992	2.2	14.1	24.3	94.7	116.6	10.2	23.9	6.3	50.2	43.2	168	59	612.7
1993	42	24.5	38.2	67.2	205.4	37.3	9.8	0	1.4	73.4	50.5	6.3	556
1994	0	0	38	78.3	98.3	17.7	9.8	1.5	20.1	136.6	219.2	25.5	645
1995	0	35.7	121	99.2	46.9	10.1	21.9	20.4	4.6	88.5	44.9	18.5	511.7
1996	8.3	0.1	103.3	108.9	121.5	10.8	13.5	0.3	7.6	20.3	59.9	11.8	466.3
1997	0	0	41.7	304.9	21.8	21.3	7.5	3	11.3	605.4	277.1	51.1	1345.1
1998	115.9	67.9	16.1	238.4	148.3	56.3	18.2	21.1	1.5	9.9	59.3	23.4	776.3
1999	0.6	1.5	71.1	81.3	66.5	23.5	8	12.4	0.7	92.1	69	29.4	456.1
2000	15.9	0	0	70.9	82.1	5	11.9	21.9	20.6	72.5	53.6	27.9	382.3
2001	16.7	21.8	140.9	179.4	18.3	9.3	6.8	16.8	12.1	20	91.2	16.5	549.8
2002	5.8	0	62.9	196.9	83.4	15.2	3	2.5	43.5	149.4	27.3	107	696.9
2003	23.2	3.8	39.3	0.8	96.3	12.6	2.7	13.9	12.3	8.6	140	20.2	373.7
2004	37.5	25.9	26.9	258.7	24.4	9.9	3.9	0.5	7.9	152.2	92	12.2	652
2005	11.4	0	10.5	93.3	117.5	21.7	10.3	2.2	3.4	23.9	57.2	0	351.4
2006	0.8	2.6	51.3	232.7	60.1	2.1	3.7	9.2	61.1	475.9	152.2	66.2	1117.9
2007	5.3	19.1	33.8	129.8	90.2	0	4.2	35.3	18.2	122.3	88.6	0.6	547.4
2008	6.2	0	87.1	176.9	67.9	43.2	11.4	9.8	10.6	185.6	53.1	3.4	655.2
2009	68.6	1.1	33.6	106.6	84.9	10.9	0	1.7	0.7	78.4	95	30.2	511.7
	20.81389	19.33056	65.99589	178.8764	121.6653	16.39306	12.94444	13.64795	19.61806	112.311	84.84444	30.35493	696.7958