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Potential Bright Spots for Flood-based Farming Systems in Turkana County, Northern Kenya

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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 development and management that uses often unpredictable and occasionally destructive water supply from ephemeral streams for various farming activities. It is climate smart agriculture that can be widely applied for crop production, agro-forest and rangeland management, domestic and livestock water supply, recharging groundwater. Flood-based farming can be expressed 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 2011). 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. Muthigani 2011, reports that 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, Rhamu Dimtu, 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 agricultural sector program, which is called as **'Drought Resilience in northern Kenya'**, 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 Turkana 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

The overall objective of the study is to introduce improved flood water utilization system to Turkana 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 Turkana County, northern Kenya.

The specific objectives of the assignment are:

Assess three or more pre-selected sites in Turkana 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

Turkana County is the largest county in Kenya, situated in North Western Kenya. In the west, it is bordered by Uganda. It is also bordered to the north and north east by Ethiopia and

South Sudan. Pokot and Baringo Counties also border it towards the south, Samburu County to the South East, and Marsabit County and Lake Turkana to the East. It shares Lake Turkana with Marsabit County. The total area of the county is estimated 77,000 Km² and lies between Longitudes 34^0 30' and 36^0 40'East and between Latitudes 1^0 30' and 5^0 30' North. Turkana County has six sub counties namely Turkana North, Turkana West, Turkana Central, Loima, Turkana South and Turkana East.

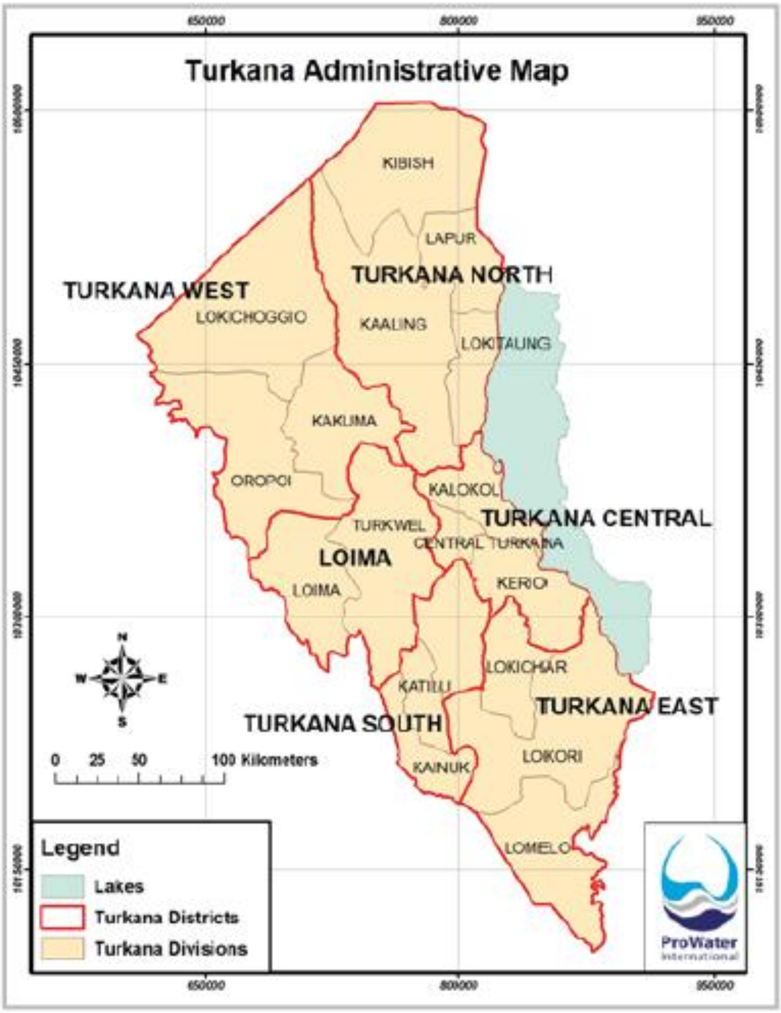


Figure 1 Turkana county administrative map (Food Security Master Plan for Turkana County, 2013)

1.3.2 Climate

According to the Food Security Master Plan for Turkana County study report, Turkana county lies within Kenya's zone V, VI and VII and is classified as arid and semi-arid lands (ASAL) characterized by warm and hot climate, in which about 65 % of it is very arid, 29 % arid, 3 % semi-arid and 3 % other lands. The temperatures range between 20 ^oC and 41 ^oC with a mean of 30.5 ^oC. The County is generally hot and dry most of the year with an average rainfall of about 150 - 550 mm. The rainfall pattern and distribution is erratic and unreliable both in time and space. There are two rainfall seasons in a year. As per the analysis undertaken using the Lodwar meteorological station's 30 years of rainfall data, the long rains (akiporo) usually occur between March and May and the short rains between October and December. The annual maximum and minimum rainfalls range between 374 and 52 mm and the mean annual is 179 mm. The driest periods (akamu) are January, February and September. The rainfall is distributed on an east-west gradient with more rainfall in the western parts and other areas of higher elevation. The rainfalls in brief violet storms resulting in flush floods. The surface runoff and potential evaporation rates are extremely high.

The study undertaken by Food Security Master Plan for Turkana County indicates that, due to the low rainfall and high temperatures there is a lot of evapotranspiration resulting into deposition of salt in the soil and capping on the surface. As a result, only about 30 % of the county's soil can be rated as moderately suitable for agricultural production. These moderately fertile soils are found at the central plains of Lorengippi, the upper Loima, the lowlands of the Turkwel, Nakaton and Kawalathe drainage along the lake at the lower Kalokol, Turkwel and Kerio rivers and a portion of the Loriu Plateaus.

For the last two and a half decades, the county has frequently suffered from failures of the annual rains. However, years 2006, 2007 and 2011, witnessed a higher than expected rainfall. This resulted to flash floods with many parts of the county experiencing loss of livestock and pasture.

1.3.3 Topography

The topography of the county is dominated by flat lowland areas with mountainous boundaries. The altitude of the county varies between 260 and 2276 m above mean sea level.

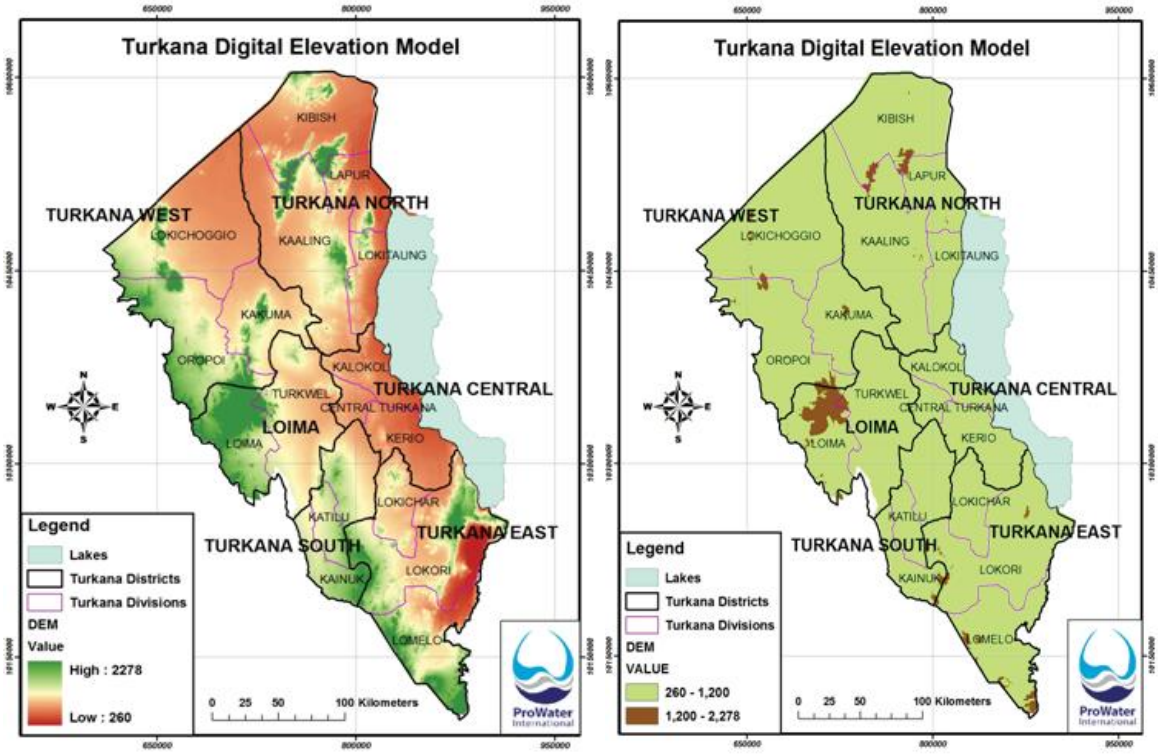


Figure 2 Topographic feature of Turkana County (Source: Food Security Master Plan for Turkana County, 2012)

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 areas are given below.

- Assess the potential of areas and sites suitable for spate irrigation in Turkana 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 Turkana 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, 1972). This model is basically developed, after several experimental results, for undertaking runoff estimates in unguaged catchments. This model 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 Lodwar is used for the analysis, mainly because of the availability of the long-term monthly rainfall data in the station and it is the only station in the county where rainfall data is available. The Lodwar meteorological station has a monthly rainfall data from 1926 to 2007, which is for 82 years. The monthly average rainfall data for all 82 years data is presented in Figure 3. 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 4.

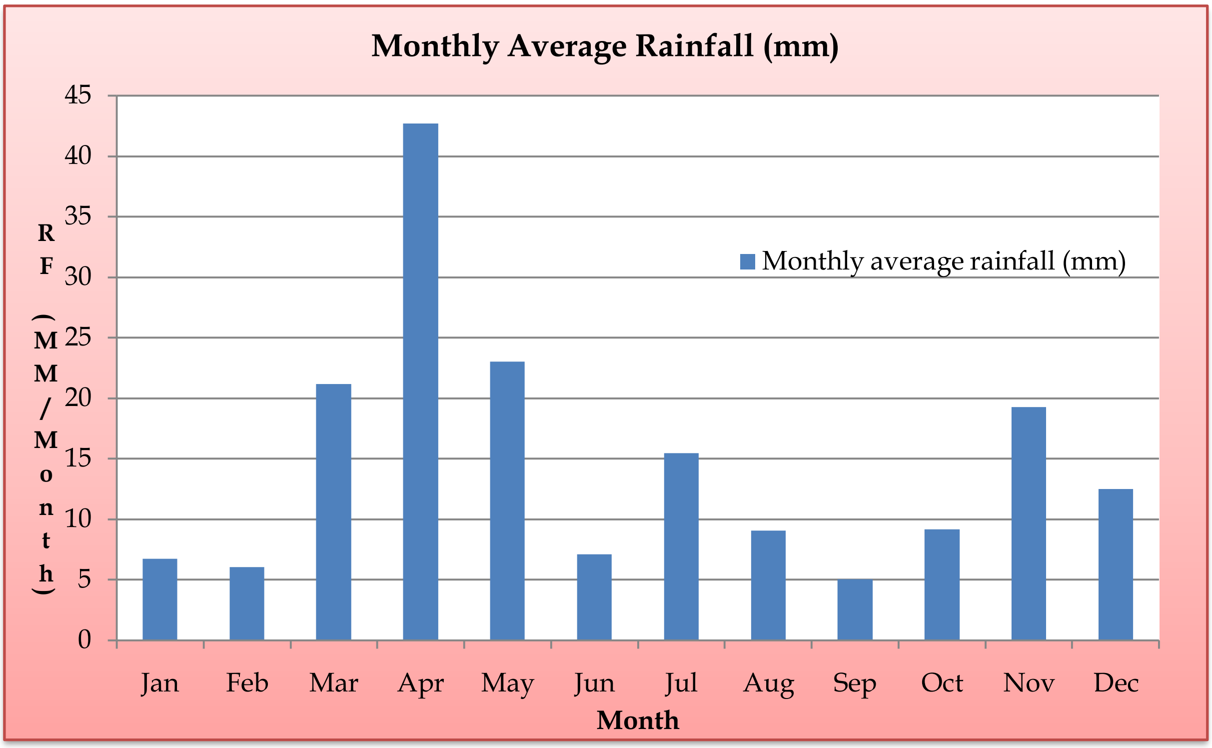


Figure 3 Monthly average rainfall of Lodwar meteorological station (from 1926 to 2007)

As it can be observed from Figure 3, the long term monthly average rainfall for Lodwar meteorological station 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 43 mm in April and 19 mm in November.

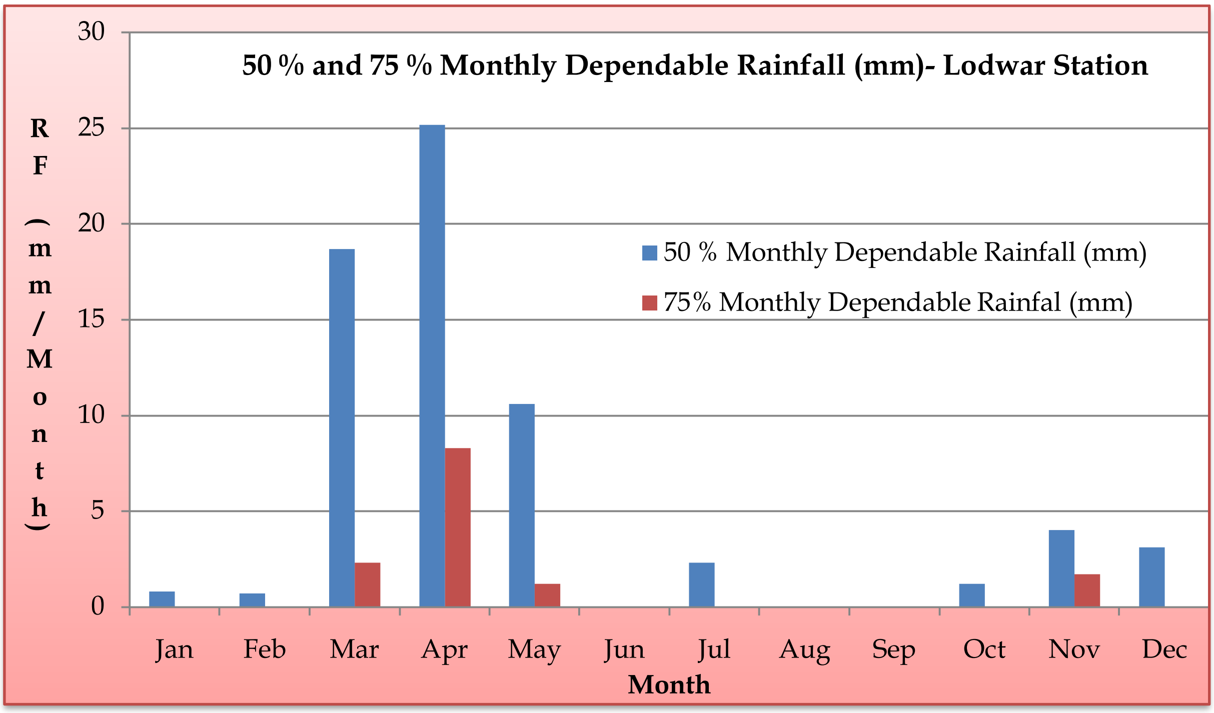


Figure 4 Monthly dependable rainfall of Lodwar Meteorological station (from 1980 to 2007)

Figure 4 shows that, the 50 % and 75 % dependable rainfall result of the Lodwar station. As a result, the rainfall with 50 % of probability can occur in both seasons with values of 28 mm and 3 mm, in April (first season) and November (second season) respectively. The rainfall with 75 % probability mainly occurs in the first season which is 28 mm, in April.

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 per the study map of the Turkana food security master plan, (depicted in figure 5 below), the major land cover is shrub savanna or trees and shrub Savana. Furthermore, the land use map prepared by the same author (figure 6), shows that the dominant land uses for Turkana county is pasture land. The ground truth from the field observation dictates to accept land cover map from the Turkana food security master plan, for the justification put below. Figure 7 shows picture taken during the flight from Lodwar to Nairobi. The picture shows that the bushes and shrubs are concentrating along the drainage networks of the Lagas/streams. The general features are consistent with the land cover map of the Turkana food security master plan. Therefore, for the overall estimation of potential direct runoff depth, weighed land use of 60 % barren land and 40 % 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 85.4. The table for Curve number is annexed.

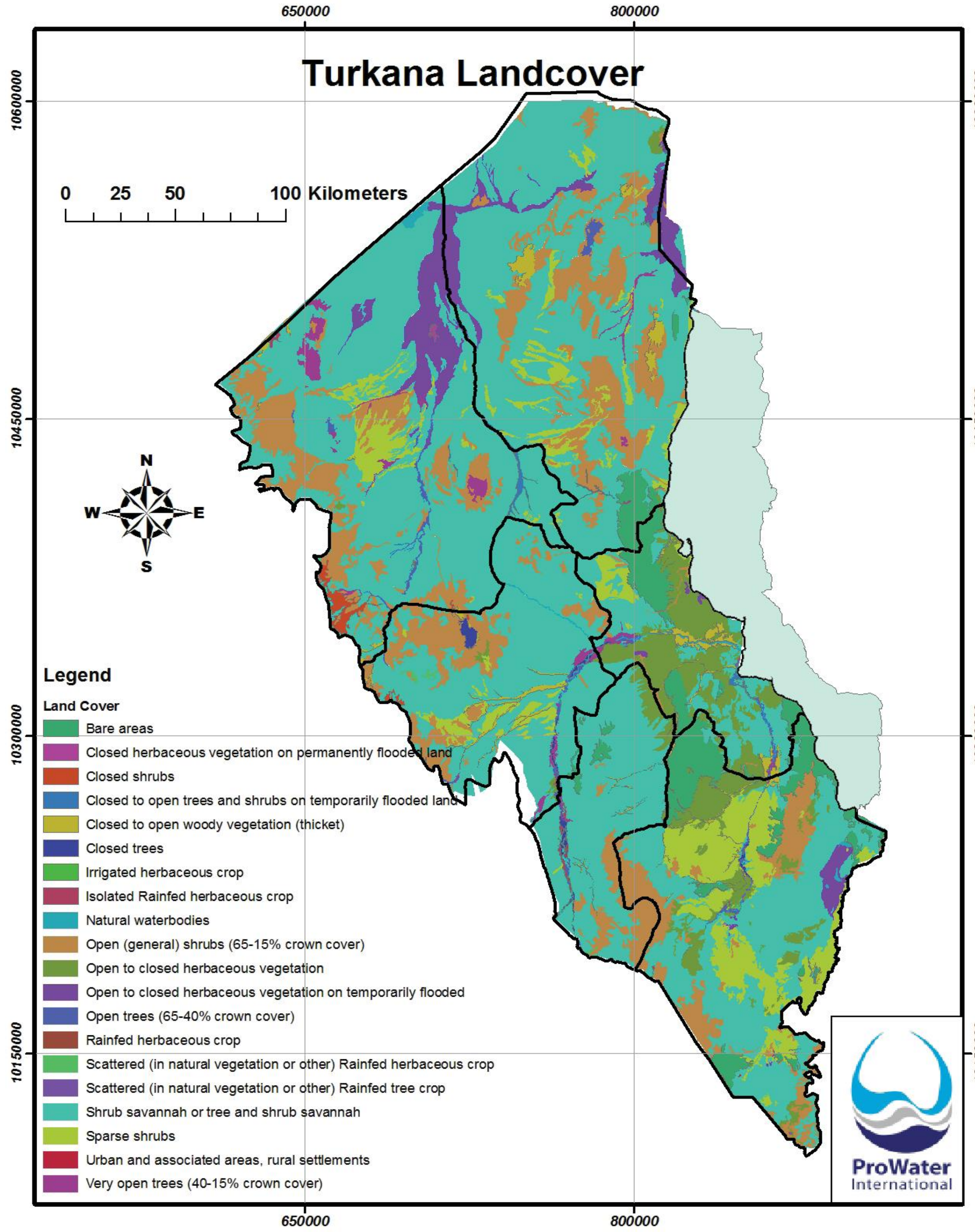


Figure 5 Land cover map of Turkana (Source: Food Security Master Plan of Turkana, 2012)

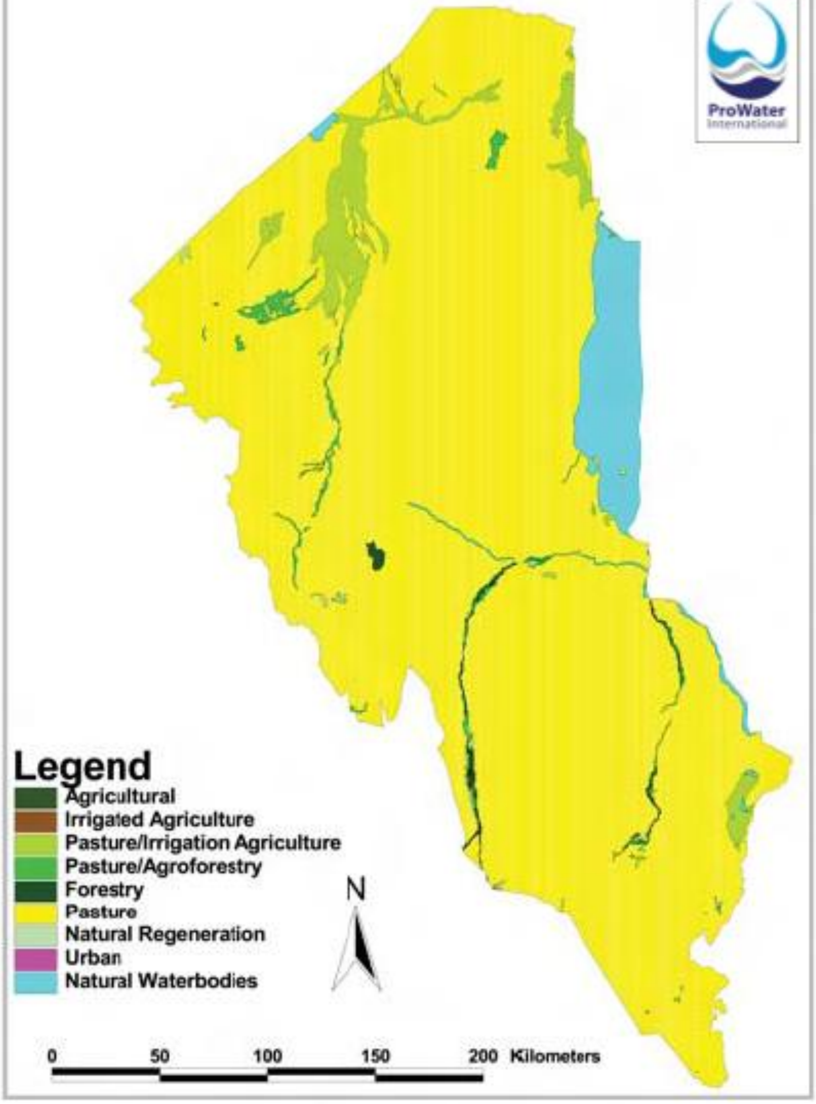


Figure 6 Land use map of Turkana county (Source: Food Security Master Plan of Turkana, 2012)

Figure 7 Photograph from airplane near Lodwar while crossing Turkana Area

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.

$$\frac{\mathbf{P-I_a-Q}}{\mathbf{S}} = \frac{\mathbf{Q}}{\mathbf{P-I_a}} \text{............ (Equation1)}$$

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 (SCS, 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:

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

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:

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

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).

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

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 will be 4.342 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 21 mm and 4.5 mm for 50 % and 75 % dependable rainfall, respectively.

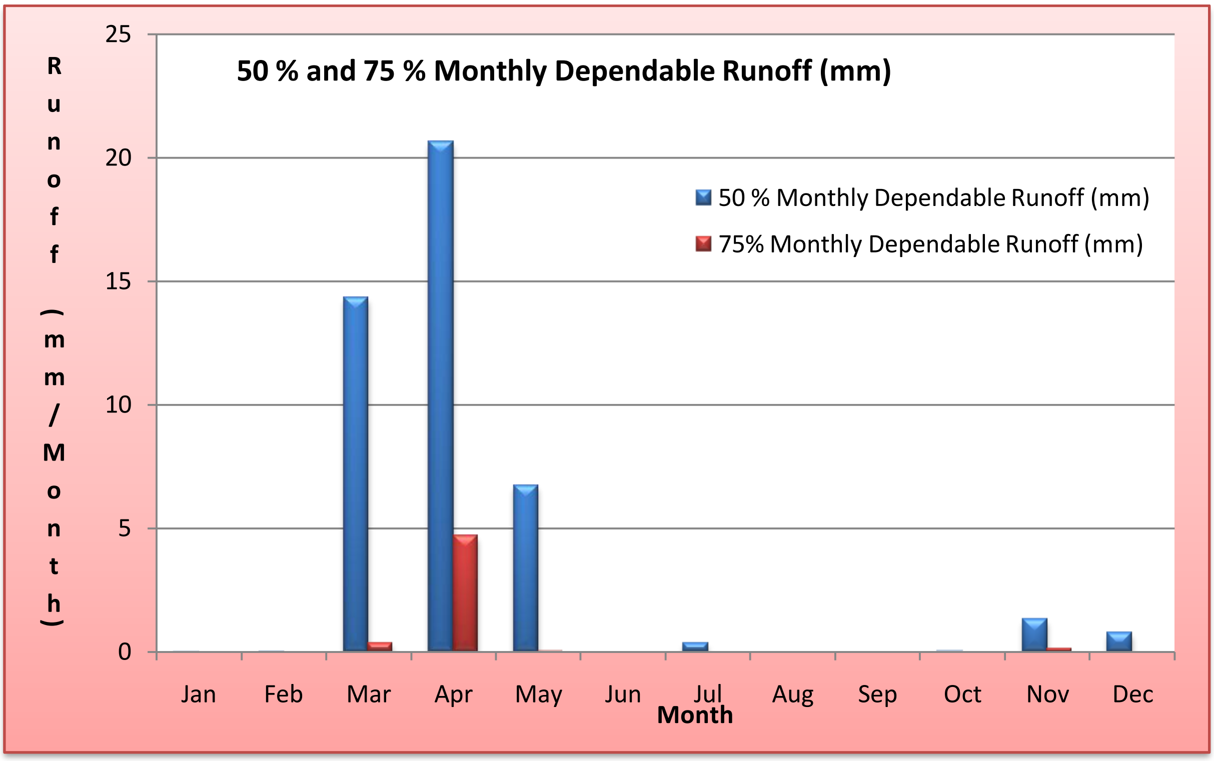


Figure 8 Direct runoff depth of Turkana County for 50 % and 75 % dependable RF

2.2 Peak Flood Estimation

As discussed in section 2.1.1 of the report, the rainfall data obtained from Lodwar meteorological station 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 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 9 to 13 below.

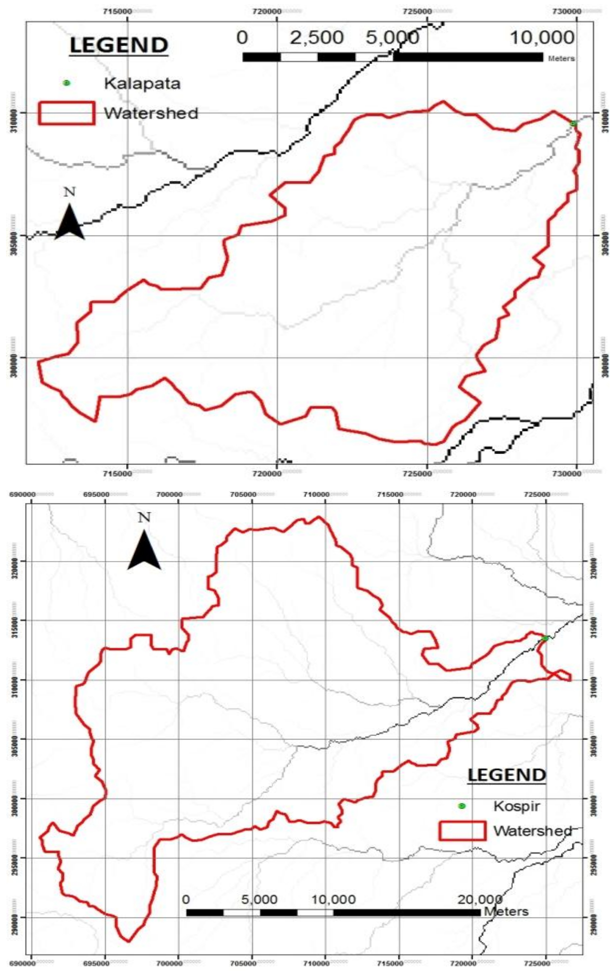


Figure 9 Watershed area of the Kalapata and Kospir schemes

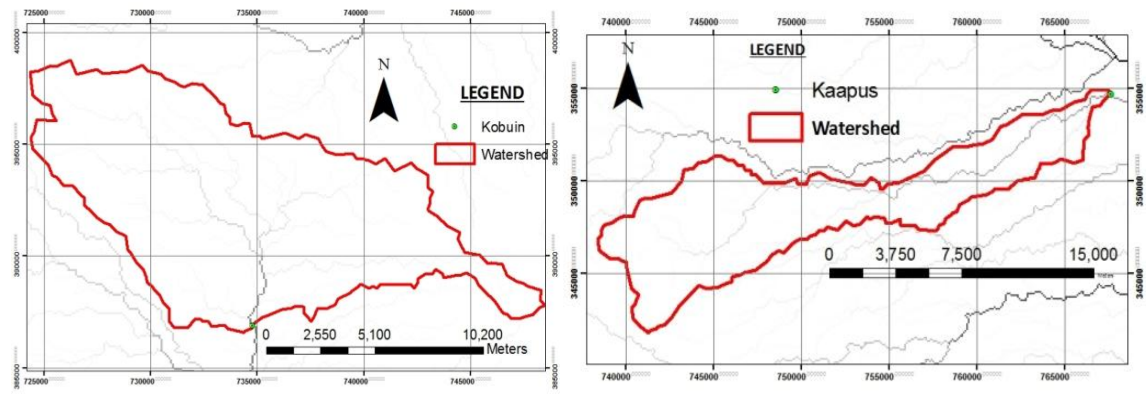


Figure 10 Watershed area of the Kobuin and Kaapus schemes

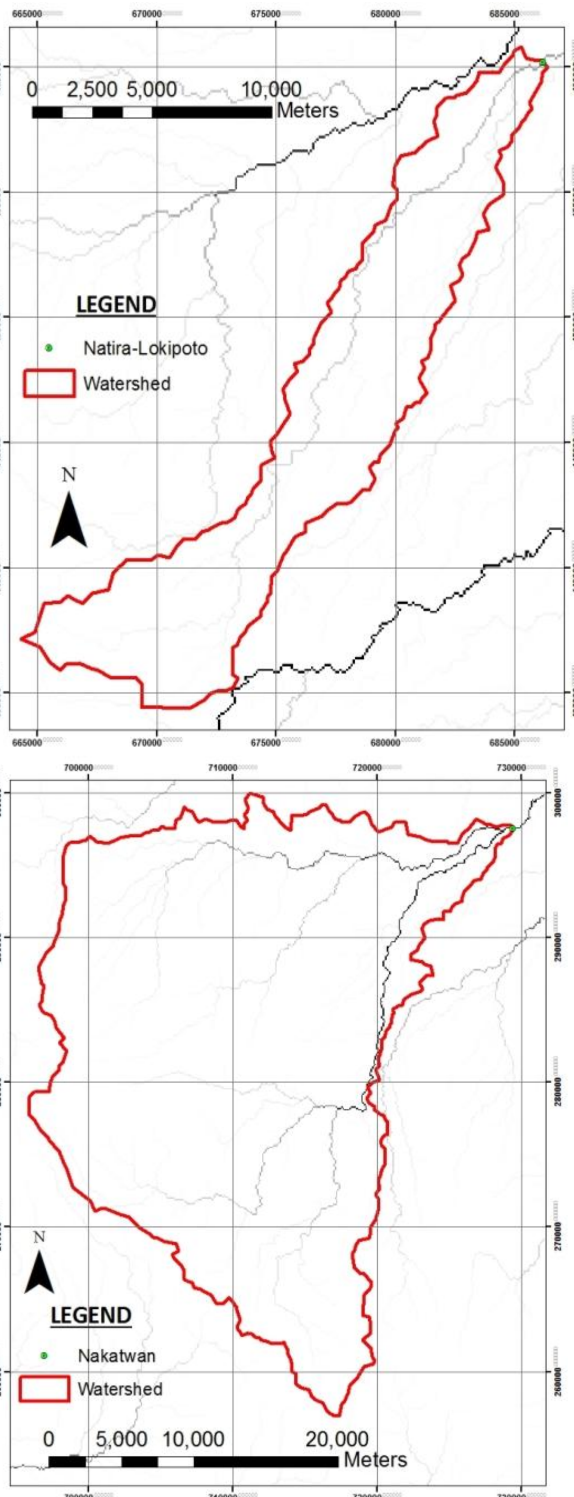


Figure 11 Watershed area of Natira-Lokipoto and Nakatwan

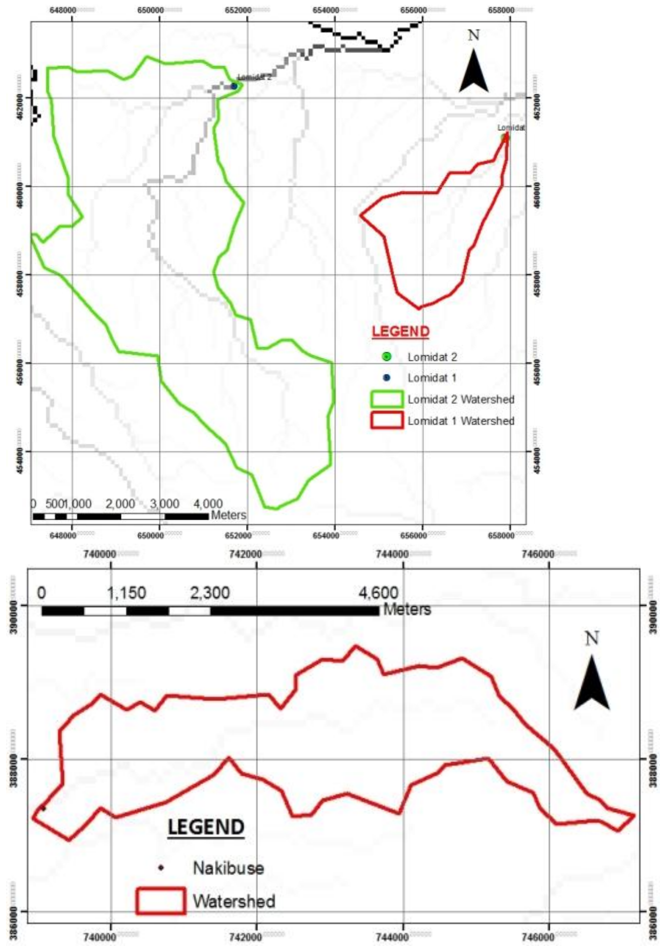


Figure 12 Watershed area of Lomidat (1 and 2) and Nakibuse schemes

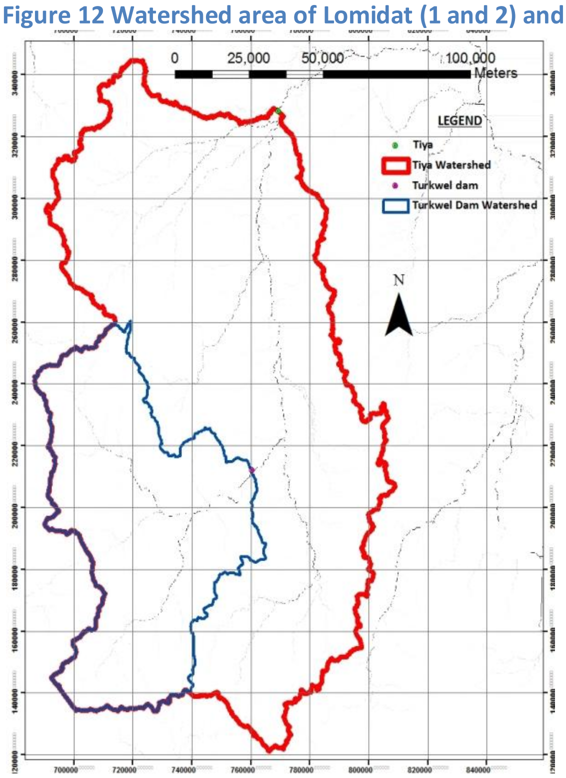


Figure 13 Watershed area of Tiya and Turk well schemes

The results are as summarized in table 1 below.

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

S.no	Scheme	Input Data			
		Catchment area (Km^2)	Main Stream Length (Km)	Mean Catchment Elevation (masl)	Mean Annual RF (mm) of Lodwar station
1	Kaapus	88	34	715	169
2	Nakibuse	8	7.5	700	169
3	Kobuin	118	18	925	169
4	Lomidat 1	27	11	980	169
5	Lomidat 2	5	3.5	760	169
6	Natira/Lokipoto	104	11	895	169
7	Nakatwan	640	48	1310	169
8	Kalapata	111	20	825	169
9	Kospir	431	44	735	169
10	Tiya (river Turkwel)	14695	207	1180	169

2.2.2 Peak Flood Estimation Using Empirical Methods

Empirical equations which are functions of mean annual rainfall, catchment area, 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 NEDECO, 1998)

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 Turkana 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	Avera ge	Max
1	Kaapus	21	18	71	19	61	192	64	192
2	Nakibuse	5	5	18	5	16	75	21	75
3	Kobuin	53	21	94	23	72	215	80	215
4	Lomidat 1	15	10	42	10	32	121	38	121
5	Lomidat 2	6	4	15	4	13	63	17	63
6	Natira/ Lokipoto	74	20	86	21	67	205	79	205
7	Nakatwan	150	52	282	59	192	417	192	417
8	Kalapata	45	21	86	22	70	210	76	210
9	Kospir	103	42	176	47	152	357	146	357
10	Tiya	1425	264	1560	353	1257	1420	1047	1560

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 Turkana 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.

3.2 Crops 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 4.33 mm/day in July while the maximum is 5.89 mm/day in February.

Table 5 Potential evapotranspiration (ETo) of the study area

Month	Min. temp (^{O}C)	Max. temp (^{O}C)	Humidity (%)	Wind speed (m/s)	Sunshine (Hrs)	Solar Radiation ($MJ/m^2/day$)	ETo (mm/day)
January	21.3	36.4	71.0	2.0	9.7	23.1	5.65
February	22.4	37.0	72.0	2.0	9.5	23.7	5.89

March	23.4	36.5	74.0	2.0	8.7	23.1	5.75
April	24.5	36.0	76.0	2.0	7.9	21.4	5.35
May	25.0	35.6	77.0	2.0	7.4	19.7	4.96
June	25.5	35.1	79.0	2.0	6.7	18.3	4.61
July	24.9	33.7	80.0	2.0	6.2	17.7	4.33
August	25.0	35.0	78.0	2.0	7.0	19.6	4.84
September	25.2	35.3	78.0	2.0	7.0	20.2	5.02
October	25.1	35.5	78.0	2.0	7.1	20.1	5.06
November	23.5	35.1	76.0	2.0	7.8	20.4	5.05
December	21.3	36.4	71.0	2.0	9.7	22.7	5.59
Average	**23.9**	**35.6**	**75.8**	**2.0**	**7.9**	**20.8**	**5.18**

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 **280.00 mm** for cowpea to **348.50 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**	
	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	
Maize	**ETc (mm/dec)**	16.5	18.9	34.7	51.4	57.8	62.0	51.7	36.3	19.5	**348.80**
	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	
Sorghum	**ETc (mm/dec)**	16.5	18.2	30.3	43.1	48.0	51.5	45.5	37.6	24.4	**315.10**
	Stage	Init	Init	Deve	Deve	Mid	Late	Late			
	Kc	0.50	0.50	0.65	0.91	1.03	1.03	0.94			
Cowpea	**ETc (mm/dec)**	27.4	26.8	33.8	46.4	51.1	54.8	39.7			**280.00**

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 Turkana County.

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

$Pe = 0.8\ P_{dep} - 24$ for $P_{dep} > 70$ 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 **3.99 l/s/ha** for both with and without effective rainfall scenario clearly indicating the insignificance of rainfall during the peak demand period.

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	16.5	18.9	34.7	51.4	57.8	62.0	51.7	36.3	19.5
		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	16.5	18.9	34.7	51.4	57.8	62.0	51.7	36.3	19.5
		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	**8.3**	**9.5**	**17.4**	**25.7**	**28.9**	**31.0**	**25.9**	**18.2**	**9.8**
Sorghum		ETc	mm/decade	16.5	18.2	30.3	43.1	48.0	51.5	45.5	37.6	24.4
		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	16.5	18.2	30.3	43.1	48.0	51.5	45.5	37.6	24.4
		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	**5.0**	**5.5**	**9.1**	**12.9**	**14.4**	**15.5**	**13.7**	**11.3**	**7.3**
Cowpea		ETc	mm/decade	27.4	26.8	33.8	46.4	51.1	54.8	39.7	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	27.4	26.8	33.8	46.4	51.1	54.8	39.7	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	**5.5**	**5.4**	**6.8**	**9.3**	**10.2**	**11.0**	**7.9**	**0.0**	**0.0**
Net irrigation requirement			mm/decade	18.7	20.3	33.2	47.9	53.5	57.4	47.4	29.4	17.1
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	**37.36**	**40.54**	**66.4**	**95.82**	**107.04**	**114.82**	**94.88**	**58.86**	**34.14**
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	3.736	4.054	6.64	9.582	10.704	11.482	9.488	5.886	3.414
			m3/day/ha	37.36	40.54	66.4	95.82	107.04	114.82	94.88	58.86	34.14
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	112.08	121.62	199.20	287.46	321.12	344.46	284.64	176.58	102.42
			l/s/ha	1.30	1.41	2.31	3.33	3.72	3.99	3.29	2.04	1.19
Maximum duty for design			l/s/ha					3.99				

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	16.5	18.9	34.7	51.4	57.8	62.0	51.7	36.3	19.5
		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	16.5	18.9	34.7	51.4	57.8	62.0	51.7	36.3	19.5
		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	**8.3**	**9.5**	**17.4**	**25.7**	**28.9**	**31.0**	**25.9**	**18.2**	**9.8**
Sorghum		ETc	mm/decade	16.5	18.2	30.3	43.1	48.0	51.5	45.5	37.6	24.4
		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	16.5	18.2	30.3	43.1	48.0	51.5	45.5	37.6	24.4
		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	**5.0**	**5.5**	**9.1**	**12.9**	**14.4**	**15.5**	**13.7**	**11.3**	**7.3**
Cowpea		ETc	mm/decade	27.4	26.8	33.8	46.4	51.1	54.8	39.7	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	27.4	26.8	33.8	46.4	51.1	54.8	39.7	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	**5.5**	**5.4**	**6.8**	**9.3**	**10.2**	**11.0**	**7.9**	**0.0**	**0.0**
Net irrigation requirement			mm/decade	18.7	20.3	33.2	47.9	53.5	57.4	47.4	29.4	17.1
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	**37.36**	**40.54**	**66.4**	**95.82**	**107.04**	**114.82**	**94.88**	**58.86**	**34.14**
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	3.736	4.054	6.64	9.582	10.704	11.482	9.488	5.886	3.414
			m3/day/ha	37.36	40.54	66.4	95.82	107.04	114.82	94.88	58.86	34.14
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	112.08	121.62	199.20	287.46	321.12	344.46	284.64	176.58	102.42
			l/s/ha	1.30	1.41	2.31	3.33	3.72	3.99	3.29	2.04	1.19
Maximum duty for design			l/s/ha					**3.99**				

3.4 Irrigation Scheduling for Turkana

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. This scheduling criterion 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 eight 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 Kaapus

The field research was attended by multidisciplinary team members that include experts from local organizations such as the Ministry of Water, Agriculture and Irrigation, GIZ Turkana and community representatives. The field research was undertaken on 17/09/2014. From the discussion with the community representatives and other stakeholders, it is learned, that the interest of the community is massive.

4.1.1 Location

Kaapus is administratively and geographically located as

- Administrative Location
    - County: Turkana
    - Sub-county: Loima
    - Ward: Turkwel
    - River/Laga: Kaapus
- Geographical location (GPS reference, UTM- WGS 1984)
    - Easting 36N 0767407
    - Northing: 0355147
    - Altitude: 550m.a.s.l

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

Kaapus is an ephemeral River which drains to the Kawalathe River. The source of flood for the Kaapus laga is from the Loima hills, which is around 35 km away from the laga. The command area that can be irrigated by the Kaapus laga can also be irrigated by the Kawalathe river but, the Kawalathe river is too deep to construct any flood diversion structure. The command area is a very thick alluvial deposit having a texture of mainly sand. Earthen bunds have been constructed, by Turkana Rehabilitation Project, to retain water for maize, sorghum and cowpea production. These bunds have been constructed parallel to the river flow which poses questions on the efficiency.

The Kaapus laga is suitable for diverting the flood using spate irrigation systems. The width and depth of the river at the diversion point is 30 m and 0.8 m respectively. 500 m lower towards the downstream side, there is a saddle point having the same width as the Kaapuss laga which needs construction of a saddle dam of height 0.8 m. its geographical location is 36N 0767685E, 0355223N. If this depression is not fully blocked, the diversion of small floods towards the Kaapus command area will be difficult.

Figure 14 Photo taken during the visit at Kaapus

Figure 15 Photo taken during the visit at Kawalathe and the Kaapus command area (left to right)

4.1.3 Floods

According to the pastoralists, the frequently observed flood mark is at 0.5 m. During the last flooding season, there were four floods and the laga was over flown by the last flooding event. The minimum, average and maximum flooding frequencies are one, three and five times per season. The area is endowed by two rainy seasons a year, the main- between end of March and June, and the minor- between September and December. The average duration of the flood ranges between 6 hours and 8 hours for small and large floods respectively.

4.2 Nakibuse

This field research was undertaken on 18/09/2014. 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 other stakeholders to ensure the interest.

4.2.1 Location

Nakibuse is administratively and geographically located as

- Administrative Location
    - County: Turkana
    - Sub-county: Turkana West
    - Ward: Nakalaale
    - River/Laga: Nakubuse
- Geographical location (GPS reference, UTM- WGS 1984)
    - Easting 36N 0739629
    - Northing: 0387213
    - Altitude: 669m.a.s.l

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

Nakupuse, which is also named as Kobuin at its further downstream, is an ephemeral River with a traditional spate .The construction of the traditional spate irrigation canals was assisted by Turkana Rehabilitation Project and the Ministry of Water Irrigation and Agriculture in the means of food for work. The Laga is the only source of domestic water supply using scooping.

The scheme is suitable for spate irrigation and has a potential for the construction of sand dams which will be integrated with spate irrigation. The challenges that the agro-pastoralists in this traditional scheme are facing are uneven distribution of water, erosion caused by the energy of the diverted flow and frequent maintenance of the open off-take. Nearby to the headwork location, there is a pond (located at 36N 0739760 E and 0387521 E) which was constructed by the Ministry of Agriculture, Water and Irrigation of the Turkana West. This pond has a capacity of 15000 m^3 and was built to improve the horticultural productivity of the area.

The width and depth of the river at the diversion point is 80 m and 0.6 m respectively and even deeper at the center reaching to 0.8 m (for 5 m width). The location of the traditional spate irrigation scheme (36N 0739444 E and 0387165 E) is 25 m upper towards the upstream side, and it is located on the outer side of a laga bend. The traditional spate irrigation systems are constructed in such a way that, there are two open off-takes having a width and depth of 5 and 0.8 m each which are spaced by 5m. The flood is diverted in to the agricultural field using bunds. The proposed diversion site construction will, therefore, enable the proper functioning of the traditional spate systems. The command area that is currently irrigated by the traditional system is 200 ha. The potential command that can be irrigated by the proposed diversion system, however, is estimated to be more than 800 ha.

Figure 16 Traditional spate diversion and canal at Nakibuse site (left to right)

4.2.3 Floods

According to the agro-pastoralists, the source of flood for this particular traditional spate system is Nadwat and Morukapel hills. The laga is also frequently overtopped. The minimum, average and maximum flooding frequencies are two, three and four times per season. The area is endowed by two rainy seasons a year, the main- between end of March and June, and the minor- between September and December. The average duration of the flood is 3 hours.

4.3 Kobuin

This field research was undertaken on 18/09/2014. In this scheme also, it can easily be observed, that the interest of the community is immense. Further discussions were also undertaken with the community representatives and other stakeholders that ensure the interest.

4.3.1 Location

Kobuin is administratively and geographically located as

- Administrative Location

  - County: Turkana
  - Sub-county: Turkana West
  - Ward: Nakalaale
  - River/Laga: Kobuin
- Geographical location (GPS reference, UTM- WGS 1984)
  - Easting 36N 0734469
  - Northing: 0387072
  - Altitude: 644 m.a.s.l

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

Kobuin is an ephemeral River which is located near to the Nakiubuse traditional spate irrigation system. In the middle of the command area, there are trapezoidal earth bunds constructed by the Turkana Rehabilitation Project and the Ministry of Water Irrigation and Agriculture in the means of food for work. The purpose of the bunds is to enhance moisture retention within the command area.

The site is ideal for flood diversion using spate irrigation. The width and depth of the river at the diversion point is 23 m and 1.0 m respectively. The second option, which is located 10 m upstream of the proposed diversion point, could also be of 26 m wide. The first option is located at the outer side of the laga bend and has a very suitable position for locating the off-take. The potential command that can be irrigated by the proposed diversion system is estimated to be more than 1000 ha.

Figure 17 Picture taken at the Kobuin laga along with its nearby command area

4.3.3 Floods

According to the agro-pastoralists, the source of flood for this particular laga is Lomiyan hills. The laga is also frequently overtopped. The minimum, average and maximum flooding frequencies are one, two and four times per season. The area is endowed by two rainy seasons a year, the main- between end of March and June, and the minor- between September and December. The average duration of the flood is one and two days for small and large floods respectively.

4.4 Lomidat

This field research was undertaken on 18/09/2014. The site is occupied by vulnerable segments of population due to either drought or livestock animals robbery. The agro-pastoralists have witnessed, that they can be lifted out of poverty through the development of small scale irrigation and other food security alternatives. We have feasted our eyes on their interest, that ensuring food security is one of the key solutions and will help to transform the bad image of the sub-county in to good image. As the people do not have enough food, they are looking for food for work type of project.

Figure 18 Discussions with the community at Lomidat

4.4.1 Location

Lomidat is administratively and geographically located as

- Administrative Location
    - County: Turkana
    - Sub-county: Turkana West
    - Ward: Songot
    - River/Laga: Lomidat
- Geographical location (GPS reference, UTM- WGS 1984)
    - Easting 36N 0657989
    - Northing: 0461080
    - Altitude: 635m.a.s.l

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

Lomidat is an ephemeral River which is located downstream of a bridge (location 36N 0657387 E, 0460066 N locally named as Nadowo) on the main road to Lokichogio and South Sudan. Another nearby bridge (location 36N 0651840 E, 0462085 N) is also the source of flood for the Nayanangitira command area. The command area is virgin and very fertile. But the main challenges of the scheme are shortage of water, expansion of Prosopis and lack of animal fence in the agricultural areas.

The site is suitable for road water diversion type of flood based farming system. The width and depth of the river at the Nadowo diversion point is 20 m and 1.0 m respectively. But for the Nayanangitira scheme, there is no defined diversion point as the flood is simply spread in to the command area. The potential command that can be irrigated by the proposed diversion systems is estimated to be more than 2000 ha.

Figure 19 Flood diversion point and culver crossing at and upstream of Lomidat site

4.4.3 Floods

According to the agro-pastoralists, the source of flood for this particular laga is Songot hills. They are also frequently overtopped. The minimum, average and maximum flooding frequencies for both lagas are one, one and three times per season. The area is endowed by two rainy seasons a year, the main- between end of March and June, and the minor- between

September and December. The average duration of the flood is seven and one days for Nadowo and Nayanangitira schemes respectively.

4.5 Natira

This field research was undertaken on 19/09/2014. The scheme is also occupied by vulnerable segments of the people. The agro-pastoralists have expressed their willingness to participate in the development of small scale irrigation and other food security alternatives as these are the only alternatives to lift them out of poverty.

4.5.1 Location

Natira is administratively and geographically located as

- Administrative Location
    - County: Turkana
    - Sub-county: Turkana West
    - Ward: Lokipoto
    - River/Laga: Natira
- Geographical location (GPS reference, UTM- WGS 1984)
    - Easting 36N 0684709
    - Northing: 0461080
    - Altitude: 635 m.a.s.l

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

Natira is an ephemeral River having a naturally suitable flood diversion point for spate irrigation and saddle point where flood can easily be diverted towards the right side command area. Flood is also scattered towards the command area from the side hills. The command areas can be supplemented by the side hill floods, if proper water harvesting interventions are introduced in the side hills.

The width and depth of the river at the Natira diversion point is 24 m and 1.5 m respectively. It is frequently overtopped by the flood generated from the Yelele catchment, a border with Uganda. The potential available command area that can be irrigated by the proposed diversion systems is estimated to be more than 1000 ha.

Figure 20 The Natira diversion site and nearby command area

4.5.3 Floods

According to the agro-pastoralists, the source of flood for this particular laga is the Yelele catchment, a border with Uganda and the side hills. The minimum, average and maximum flooding frequencies for laga are one, four and six times per season. The area is endowed by two rainy seasons a year, the main- between end of March and June, and the minor- between September and December. The average duration of the flood is four hours.

4.6 Nakatwan

This field research was undertaken on 20/09/2014. This scheme is also one of the food insecure parts of the Turkana County. The agro-pastoralists have articulated their eagerness towards the development of small scale irrigation and other food security alternatives as these are the only alternatives to lift them out of poverty.

4.6.1 Location

Nakatwan is administratively and geographically located as

- Administrative Location
    - County: Turkana

  - Sub-county: Loima
  - Ward: Lobei
  - River/Laga: Nakatwan
- Geographical location (GPS reference, UTM- WGS 1984)
  - Easting 36N 0728064
  - Northing: 0297538
  - Altitude: 802m.a.s.l

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

Nakatwan is an ephemeral River having a natural diversion point, suitable for spate irrigation, towards the left side command area. The command areas are only limited to the left side of the river flow. The width and depth of the river at the Nakatwan diversion point is 66 m and 0.6 m respectively. It is frequently overtopped by the flood generated from the Tamanak catchment. Even though, the command that can be irrigated by the proposed diversion systems, is characterized by undulating nature and sandy in texture, its potential is estimated to be more than 500 ha. These command area is covered with sparsely scattered acacia trees.

Figure 21 The Nakatwan diversion site along with its nearby command area

4.6.3 Floods

According to the agro-pastoralists, the source of flood for this particular laga is the Tamanak hills. The minimum, average and maximum flooding frequencies for laga are two, three and six times per season. The area is endowed by two rainy seasons a year, the main- between end of March and June, and the minor- between September and December. The average duration of the flood is three days.

4.7 Kalapata

This field research was undertaken on 20/09/2014. Similar to the other sites, this site is also one of the food insecure parts of the Turkana County. The agro-pastoralists were demanding on the development of small scale irrigation and other food security alternatives as these are the only alternatives to elevate them out of poverty.

4.7.1 Location

Kalapata is administratively and geographically located as

- Administrative Location

    - County: Turkana
    - Sub-county: Loima
    - Ward: Lochor-Emeyan
    - River/Laga: Kalapata
- Geographical location (GPS reference, UTM- WGS 1984)
    - Easting 36N 0730125
    - Northing: 0309651
    - Altitude: 734m.a.s.l

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

Kalapata is an ephemeral River with the only source of runoff/moisture for the surrounding command areas. The command areas can also be supplemented by a small laga (located 36N 0729962 E, 0309635N) having 10 m width and 2 m deep gorge. These two lagas supplement moisture to the command area with the support using the construction of semi-circular bunds built within the command area.

The width and depth of the Kalapata River at the diversion point is 30 m and 3.0 m respectively. It is frequently overtopped by the flood generated from the Tamanak catchment. Even though, the command that can be irrigated by the proposed diversion systems, is characterized by undulating nature and sandy in texture, its potential available command area is estimated to be more than 500 ha.

Figure 22 Command area of the Kalapata site and the nearby small laga

4.7.3 Floods

According to the agro-pastoralists, the source of flood for this particular laga is the Pero hills. The minimum, average and maximum flooding frequencies for the laga are two, three and seven times per season. The area is endowed by two rainy seasons a year, the main- between end of March and June, and the minor- between September and December. The average duration of the flood is four to six hours.

4.8 Kospir

This field research was undertaken on 20/09/2014. This scheme is also one of the food insecure parts of the Turkana County.

4.8.1 Location

Kospir is administratively and geographically located as

- Administrative Location

- County: Turkana
- Sub-county: Loima
- Ward: Lochor-Emeyan
- River/Laga: Kospir

- Geographical location (GPS reference, UTM- WGS 1984)
  - Easting 36N 0725002
  - Northing: 0313531
  - Altitude: 752m.a.s.l

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

Kospir is an ephemeral River with the possibility of constructing a subsurface sand dam. Its width is around 180 m and both abutments are made of basaltic rock with a possible extension towards the foundation at shallow depth. There was also a small stream flow during the field visit.

Figure 23 The Kospir sand dam site location with its left side abutment

4.9 Tiya

This field research was undertaken on 20/09/2014. This scheme is also one of the food insecure parts of the Turkana County. The agro-pastoralists were demanding on the development of small scale irrigation and other food security alternatives as these are the only alternatives to elevate them out of poverty.

4.9.1 Location

Tiya is administratively and geographically located as

- Administrative Location
  - County: Turkana
  - Sub-county: Loima
  - Ward: Kaitese
  - River/Laga: Turkwell River
- Geographical location (GPS reference, UTM- WGS 1984)
  - Easting 36N 0771852
  - Northing: 0327900
  - Altitude: 558m.a.s.l

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

Turkwell is a perennial River with many river diversion schemes built upstream of it. It is the only source of irrigation water for the surrounding command areas. It is also supplemented by the regulated release from the Turkwel hydropower dam which is located at its upstream. Immediate upstream of the proposed river diversion scheme, there is a river diversion structure which is under construction (located 36N 0770556E, 0327288N) which serves for 750 households. So the construction of the proposed river diversion scheme could cause some conflict between upstream and downstream users. The other problem of the proposed river diversion is, that the agro-pastoralists are new to irrigation and administering the water management between 600 households could be difficult. The issue of ownership could also be one of the problems that need to be addressed.

The width and depth of the Turkwel river at the diversion point is 90 m and 2.0 m respectively. It is frequently overtopped by the flood generated from the Loima catchment. The command that can be irrigated by the proposed diversion system is estimated to be more than 500 ha.

Figure 24 Tiya diversion location and its command area

Figure 25 Existing off-take at Tiya and its main canal

4.9.3 Floods

According to the agro-pastoralists, the sources of flood for this particular laga are the Turkwel hydropower dam and the Loima hills. As it is a perennial river, no further information is required about the flooding duration and frequency.

4.10 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 0.7 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	Kaapu	88	50%	97	598	1,261,878	1,816,914	592,147	0	31,233	0	0	2,069	115,464	66,659	3,887,058	71
			75%	0	0	31,233	412,779	2,069	0	0	0	0	0	11,760	0	457,841	0
2	Nakibuse	8	50%	9	54	114,716	165,174	53,832	0	2,839	0	0	188	10,497	6,060	353,369	6
			75%	0	0	2,839	37,525	188	0	0	0	0	0	1,069	0	41,622	0
3	Kobuine	118	50%	129	802	1,692,063	2,436,316	794,015	0	41,880	0	0	2,775	154,826	89,384	5,212,192	95
			75%	0	0	41,880	553,499	2,775	0	0	0	0	0	15,769	0	613,923	0
4	Lomidat 1	27	50%	30	184	387,167	557,462	181,681	0	9,583	0	0	635	35,426	20,452	1,192,620	22
			75%	0	0	9,583	126,648	635	0	0	0	0	0	3,608	0	140,474	0
5	Lomidat 2	5	50%	5	34	71,698	103,234	33,645	0	1,775	0	0	118	6,560	3,787	220,856	4
			75%	0	0	1,775	23,453	118	0	0	0	0	0	668	0	26,014	0
6	tira/Lokip	104	50%	114	707	1,491,310	2,147,262	699,810	0	36,911	0	0	2,446	136,457	78,779	4,593,796	84
			75%	0	0	36,911	487,830	2,446	0	0	0	0	0	13,898	0	541,085	0
7	Nakatwan	640	50%	702	4,352	9,177,291	13,213,918	4,306,523	0	227,147	0	0	15,050	839,737	484,796	28,269,514	518
			75%	0	0	227,147	3,002,028	15,050	0	0	0	0	0	85,528	0	3,329,753	2
8	Kalapata	111	50%	122	755	1,591,686	2,291,789	746,913	0	39,396	0	0	2,610	145,642	84,082	4,902,994	90
			75%	0	0	39,396	520,664	2,610	0	0	0	0	0	14,834	0	577,504	0
9	Kospir	431	50%	473	2,931	6,180,332	8,898,748	2,900,174	0	152,969	0	0	10,135	565,510	326,479	19,037,751	349
			75%	0	0	152,969	2,021,678	10,135	0	0	0	0	0	57,598	0	2,242,380	1

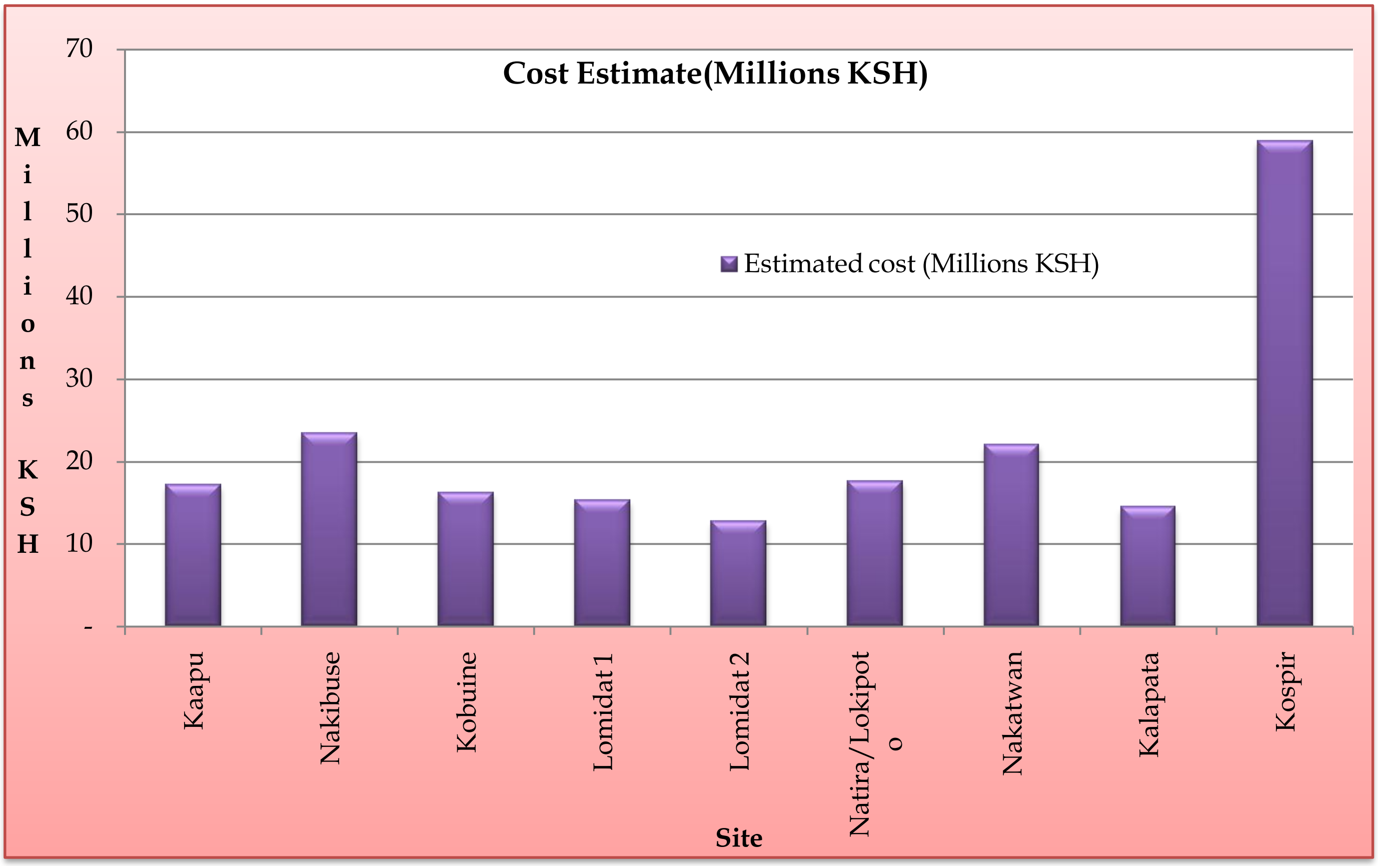
4.11 Cost Estimation

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 Kaapus site is presented for reference in table 10.

Table 10 Sample rough cost estimate for Kaapuss

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	579	258,309
1.2	Backfilling and Compaction	cubic m	186	1,456	270,872
1.3	Masonry work	cubic m	368	10,000	3,675,000
1.4	Plastering work	square m	507	1,000	507,426
1.5	Site clearance	square m	3,200	150	480,000
1.6	Concrete	cubic m	10	25,000	250,000
2	**Wing walls**			-	
2.1	Excavation	cubic m	737	579	426,725
2.2	Backfilling and Compaction	cubic m	458	1,456	666,286
2.3	Masonry work	cubic m	458	5,854	2,678,482
2.4	Plastering work	square m	28	495	13,846
3	**Head regulator**			-	
3.1	Excavation	cubic m	51	579	29,772
3.2	Backfilling and Compaction	cubic m	32	1,456	46,485
3.3	Masonry	cubic m	32	5,854	186,871
3.4	Plastering	square m	2	495	1,187
3.5	Concrete pipe 0.6 m diameter	number	7	9,000	63,000
4	**Materials**				
4.1	Steel plate (for under sluice)				-
	(1.0m X1.0m X 3mm)	Pcs	7	25,000	175,000
4.2	Steel plate (for head reg. gates)				-
	(0.8m X 0.6m X 3mm)	Pcs	1	5,000	5,000
4.3	Angle iron				-
	40mm X 40mm X 6m for gate reinforcement and grooves	Pcs	15	3,500	52,500
4.4	10mm diam R. bar	Pcs	4	750	3,000
4.5	Rubber seal	m	50	2,500	125,000
5	**Canals**			-	
5.1	Excavation on loose to medium soil	cubic m	3,200	579	1,851,680
5.2	Backfilling and Compaction	cubic m	500	1,456	728,150
5.3	Masonry work	cubic m	300	5,854	1,756,305
5.4	Plastering work	square m	28	495	13,846
6	***Total investment Cost***				**14,264,743**
7	***Operation and maintenance cost+Contigency (20%)***				**2,852,949**
8	***Total Project Cost***				**17,117,691**

Figure 26 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

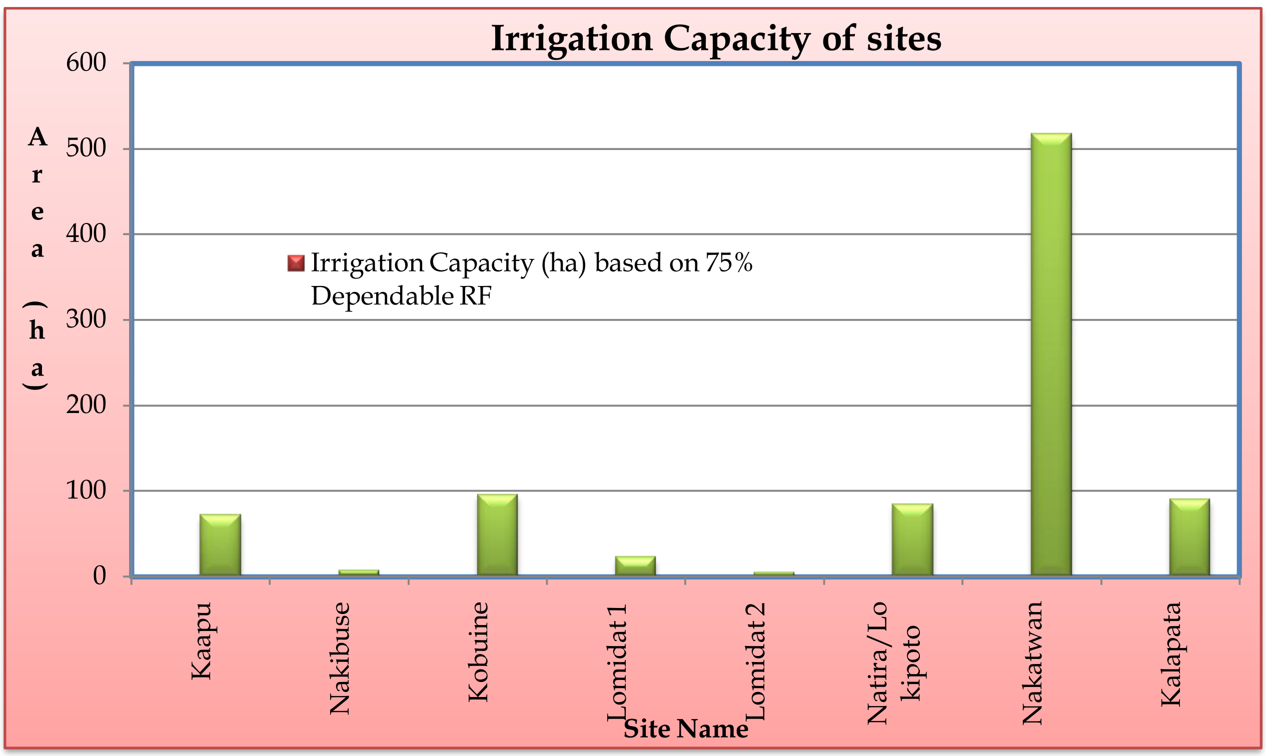


Figure 27 Irrigable area for both 50% and 75% dependable rainfalls for the sites in Turkana County

Figure 27 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 no possibility of irrigation. It means that the rainfall is highly unreliable and it is not possible to cultivate an area with probability of 75% of success in a year. It also shows that it is possible to irrigate some areas in the county with a success probability of 50%. This means that there is a 50% of chance to harvest or not to harvest. Nakatwan, Kobuin, Kalapata, Kaapus and and Natira/Lokipoto are in their rank for irrigating more land. Nakibuse, Lomidat 2 and Lomidat 1 are irrigating 4 ha, 6 ha and 22ha of land respectively with a probability of success of 50 %.

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.

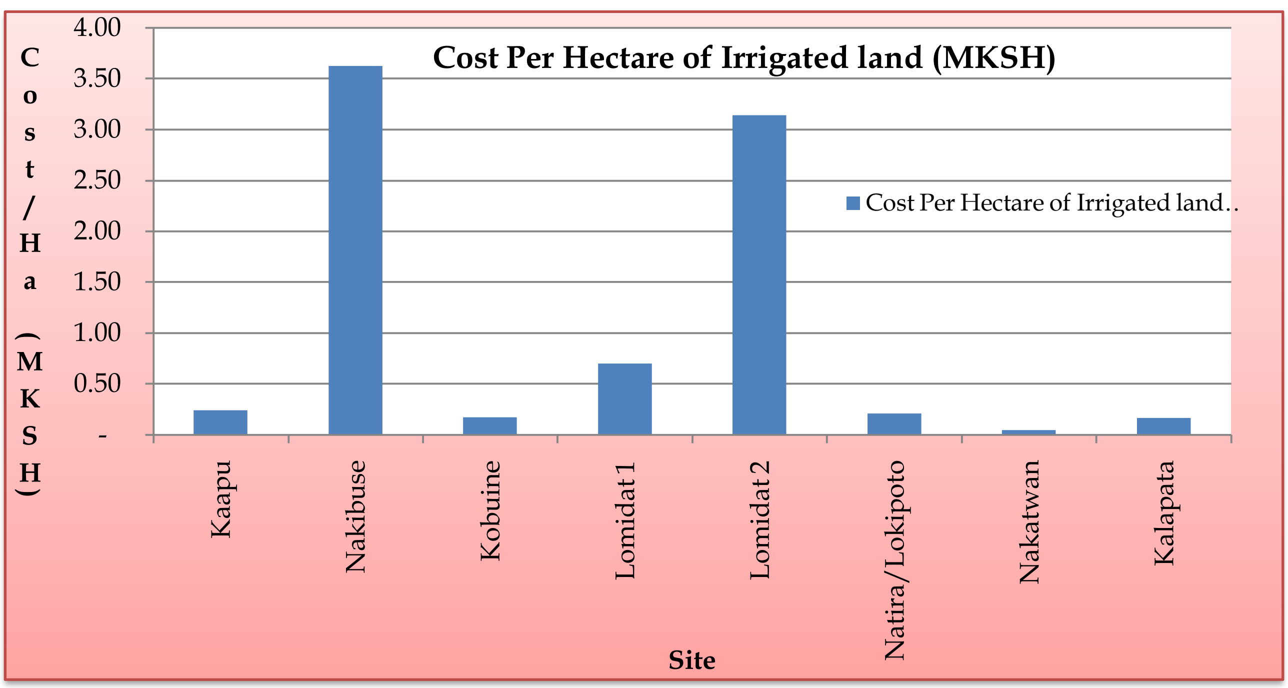


Figure 28 Cost per hectare in Kenyan Shilling for the sites identified in Turkana

Figure 28 shows cost of investment per hectare of irrigable land. The costs per ha for Nakibuse and Lomidat 2 are very high, it is 3.63 and 3.1 million KSH/ha respectively. In contrast the cost per ha for Nakatwan, Kalapata, Kobuin, Kaapus, Natira and Lomidat 1 are 43,000, 161,000, 170,000, 209,000 and 699,000 KSH, which is much less than the costs of Nakibuse and Lomidat 2. The figure indicates that the relative investment cost is low in Nakatwan and high in Nakibuse and Lomidat 2.

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

From the observation of the team, Nakatwan, Kalapata and Kobuin are suitable for implementing flood based farming systems. Therefore, from the potential irrigable land and investment cost per hectare of irrigable land, Nakatwan, Kalapata and Kobuin are relatively more feasible sites than others. Hence it is recommended to introduce the technology to Turkana County with a detail feasibility study and design of the three sites i.e Nakatwan, Kalapata and Kobuin. The best site from which the other areas can learn would be decided after that.

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 County 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 some shallow Lagas (seasonal streams) suitable for low-cost and low maintenance flood diversion structures;
- Some Lagas are also ideal for construction of sub-surface dams to serve dual purposes, namely, for flood-diversion and domestic water supply;
- 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.

The implementation of such development projects, however, requires well trained human resources capacity specific to the field of flood-based farming. According to the evaluation made, the county experts have the interest and basic knowledge of flood based farming systems. Because, among the sites pre-selected by the county experts have been found suitable for spate irrigation and their on-field input was vital. However, the design, construction and management of flood-based farming systems is very challenging as it differs substantially from conventional irrigation. Practical oriented training and subsequent coaching is required during the initial stage of the flood based farming systems development. 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, 4 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 29). 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.

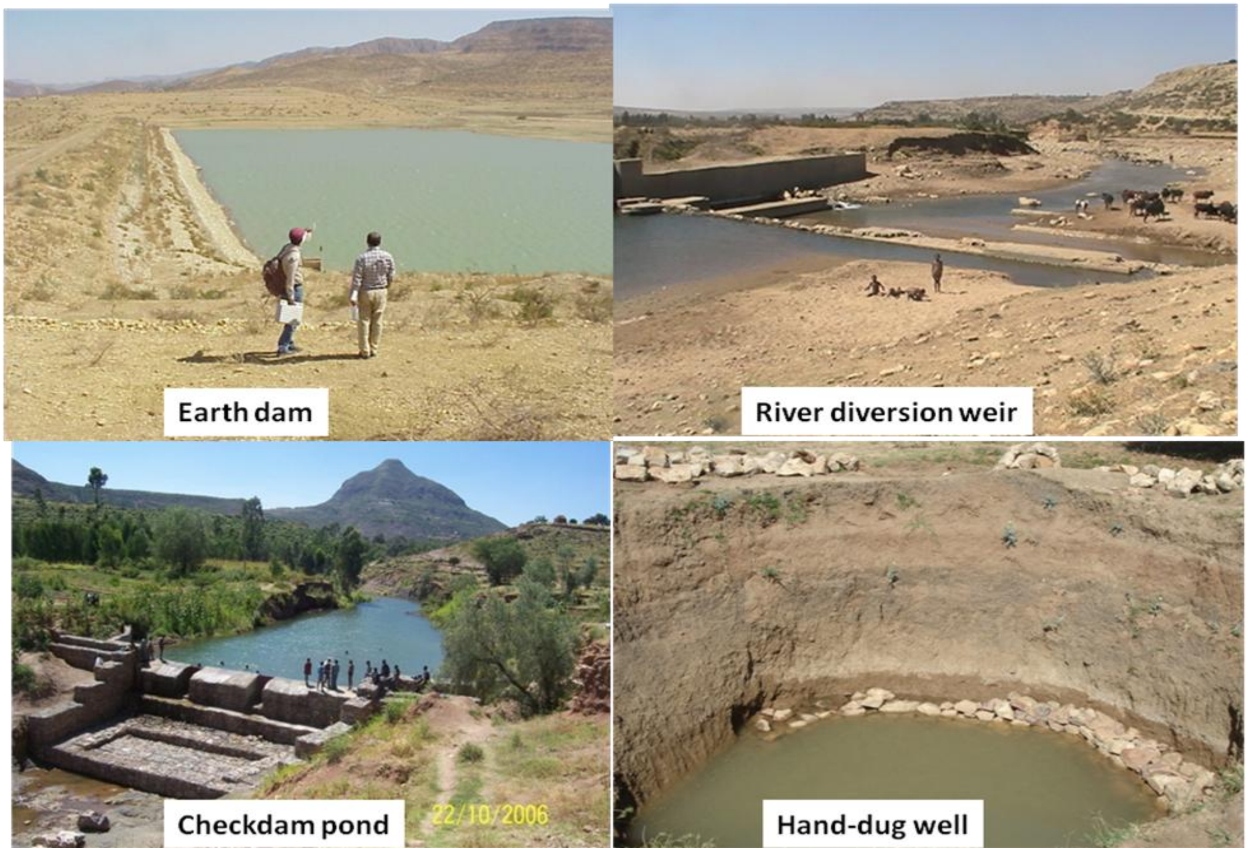


Figure 29 Some of the watershed management water harvesting techniques in Tigray in addition to FBFS

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 6 sub-counties in Lodwar 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, the following concluding remarks have been forwarded:

- Flood based farming can be considered as an alternative for supporting the agricultural system in Turkana 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 Turkana 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 518 ha, 95 ha, 90 ha, 84 ha and 71 ha of land in Nakatwan, Kobuin, Kalapata, Kaapus and Natira/Lokipoto respectively and the rest have almost negligible irrigation potential.
- The 75 % dependable rainfall analysis indicates that, there is no possibility of irrigation in all visited sites in the county.
- The construction of modern flood based farming structures in Nakibuse, Lomidate 2 and Lomidat 1 are relatively expensive compared to the other sites.
- The overall evaluation indicates that, Nakatwan, Kobuin and Kalapata are the best sites.

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, Irrigation and Water has to be improved.
- Further detail study and design is recommended to choose the best site among the three sites chosen (Nakatwan, Kobuin and Kalapata).
- 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 Turkana, 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 learned that this is a practice in most developing countries, where several technologies fail or 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 to one another with the flood base farming systems.
- The Consultants propose delivery of short term training to relevant experts from the 6 sub-counties in Lodwar.
- 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.

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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 Lodwar Metrological Station

Year	January RF(mm)	February RF(mm)	March RF(mm)	April RF(mm)	May RF(mm)	June RF(mm)	July RF(mm)	August RF(mm)	September RF(mm)	October RF(mm)	November RF(mm)	December RF(mm)	Rank (m)	January Decending	February Decending	March Decending	April Decending	May Decending	June Decending	July Decending	August Decending	September Decending	October Decending	November Decending	December Decending	Probability of Occurrence P=m/(N+1)	Annual RF (mm)
1980	0.8	0	1.4	0	32.9	0	0	0	0	0.3	20	0	1	58.9	30.5	87.8	123.3	130.6	52.7	73.2	52.4	71.4	46.2	164.6	106.1	0.0323	55.4
1981	0	0	43.6	13.6	1.7	0	0	1.8	0	0.6	0	0	2	23.5	29.2	79.7	92.9	77.3	41.6	45.5	48	39.4	42.2	154.1	70.7	0.0645	61.3
1982	0	30.5	32.6	29	16.6	0	0.7	0	1.2	5.6	164.6	70.7	3	20.2	21.2	48	87	70.7	40.4	36.1	37	28.9	41.9	139.6	57.7	0.0968	351.5
1983	0	15.2	0	1.9	5.2	0	14.9	25.6	22.8	1.5	1.8	17.7	4	14.2	19.6	46.2	79.9	68.6	23.5	31.6	27.1	26.2	30	39.8	47.4	0.1290	106.6
1984	8.5	0	4	25.2	0	0	0.8	0	0	0	1.7	11.5	5	13.1	15.2	43.6	79.4	53.4	10.4	29.4	26.6	22.8	19.4	31.2	20.2	0.1613	51.7
1985	20.2	0.7	32.8	71.4	68.6	0	5.7	0	0	0	3.1	0	6	10	8.9	43.4	71.4	38.6	5.2	29	25.6	19.4	15.8	27.6	17.7	0.1935	202.5
1986	0	3.9	41.5	79.9	1.5	23.5	0	1.4	0	0	1.7	4.3	7	9	6.3	41.5	66.2	38.5	2.8	20.2	13.4	16.4	8.8	22.4	16	0.2258	157.7
1987	0.8	0	0	79.4	38.4	40.4	0	0	0	0	22.4	0	8	8.5	5.3	39	61.8	38.4	1.6	14.9	10.7	5.1	8.5	20	11.5	0.2581	181.4
1988	2.7	0	0.5	87	6.1	1.5	73.2	48	71.4	8.5	0.3	2.4	9	6.1	4.3	35.9	56.6	32.9	1.5	13.3	8.6	1.2	8.5	13.5	9.2	0.2903	301.6
1989	0	19.6	48	8.1	70.7	0	29	0	39.4	0	6.3	47.4	10	4.6	3.9	34.5	50.8	30	1.4	5.7	2.5	1.2	5.6	6.3	6.2	0.3226	268.5
1990	1.1	21.2	13.6	18	4.1	0	0	0	0	15.8	0	6.2	11	2.7	3.6	34.4	36.5	20.8	0.8	5.1	1.8	0.2	5.1	6.1	5.5	0.3548	80
1991	14.2	0.4	46.2	8.3	38.5	0	4.9	8.6	0	8.8	1.1	2	12	1.1	3.1	32.8	29	19.2	0	4.9	1.4	0	2.9	5.4	4.8	0.3871	133
1992	0	3.6	14.4	16.8	10.6	0.8	0	0.4	0	2.9	6.1	2	13	1.1	1.9	32.6	27.4	16.6	0	4.5	1.4	0	1.6	4.8	4.4	0.4194	57.6
1993	9	8.9	2.6	0.5	77.3	10.4	0	0	0	0	4	0	14	1	1	18.9	27.3	13.2	0	3.7	0.4	0	1.5	4.1	4.3	0.4516	112.7
1994	0	1	18.9	50.8	7.5	1.4	4.5	10.7	0	8.5	27.6	0.4	15	0.8	0.7	18.7	25.2	10.6	0	2.3	0	0	1.2	4	3.1	0.4839	131.3
1995	0	6.3	9.1	27.3	0	2.8	2.3	1.4	19.4	1.6	0	3.1	16	0.8	0.4	17.4	23.3	7.5	0	1.2	0	0	1	3.5	2.4	0.5161	73.3
1996	6.1	1.9	35.9	23.3	19.2	52.7	45.5	0	0	0	13.5	0	17	0.6	0	14.4	18	6.1	0	0.8	0	0	0.7	3.1	2	0.5484	198.1
1997	0	0	2	123.3	0.4	0	36.1	37	0	30	139.6	5.5	18	0	0	13.6	16.8	5.6	0	0.7	0	0	0.6	2.8	2	0.5806	373.9
1998	13.1	5.3	2.3	13.4	20.8	41.6	1.2	26.6	0	0	0.6	0	19	0	0	9.1	13.6	5.2	0	0	0	0	0.3	2.3	1	0.6129	124.9
1999	0	0	43.4	27.4	5.6	0	13.3	0	0	0.7	4.1	9.2	20	0	0	4	13.4	4.1	0	0	0	0	0	2.1	0.5	0.6452	103.7
2000	0	0	0	9.5	0	0	3.7	0	0	41.9	4.8	16	21	0	0	4	9.8	1.7	0	0	0	0	0	1.8	0.4	0.6774	75.9
2001	23.5	3.1	34.4	6.6	0	0	20.2	2.5	1.2	5.1	2.1	1	22	0	0	2.6	9.5	1.5	0	0	0	0	0	1.7	0	0.7097	99.7
2002	10	0	87.8	56.6	130.6	1.6	0	0	0	19.4	5.4	20.2	23	0	0	2.3	8.3	1.2	0	0	0	0	0	1.7	0	0.7419	331.6
2003	0	0	79.7	61.8	38.6	0	0	13.4	0	0	0	4.8	24	0	0	2	8.1	0.8	0	0	0	0	0	1.1	0	0.7742	198.3
2004	58.9	0	4	66.2	13.2	0	0	0	26.2	1.2	39.8	4.4	25	0	0	1.4	7.8	0.4	0	0	0	0	0	0.6	0	0.8065	213.9
2005	0.6	0	17.4	7.8	0	5.2	31.6	0	28.9	0	2.3	0	26	0	0	0.5	6.6	0	0	0	0	0	0	0.3	0	0.8387	93.8
2006	1.1	4.3	34.5	36.5	1.2	0	5.1	27.1	0.2	46.2	154.1	57.7	27	0	0	0	1.9	0	0	0	0	0	0	0	0	0.8710	368
2007	0	29.2	18.7	92.9	53.4	0	29.4	52.4	16.4	0	3.5	0.5	28	0	0	0	1.4	0	0	0	0	0	0	0	0	0.9032	296.4
2008	1	0	39	9.8	0.8	0	0	0	5.1	42.2	31.2	0	29	0	0	0	0.5	0	0	0	0	0	0	0	0	0.9355	129.1
2009	4.6	0	0	1.4	30	0	0	0	0	1	2.8	106.1	30	0	0	0	0	0	0	0	0	0	0	0	0	0.9677	145.9
																										Max	373.9
																										Min	51.7
																										Average	169.31

Rainfall data of Lodwar Metrological Station

	KENYA METEOROLOGICAL DEPARTMENT												
	READINGS OF MONTHLY RAINFALL AMOUNTS IN MILLIMETRES												
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
1926	0	0	0	75.2	35.3	0	40	0	16.3	0	9.1	0	175.9
1927	11.4	0.3	6.9	31.3									49.9
1928	0	2	0	0	0	0	0	0	0	0	0	0	2
1929	0	0	0	2	0	0	45.5	0	0	0	0	37.8	85.3
1930	0	24.1	0	78.1	1.5	0	11.5	0	0	0	0	30.5	145.7
1931	1	0	0	14.3	13.3	0	11.1	7.1	14.5	0	0.8	1	63.1
1932	0	1.8	41.6	15.5	43.5	0	5.9	1.3	0	2	1	5.6	118.2
1933	0	0	0	0	3.3	0	0.3	0	0	12.5	2.5	0	18.6
1934	0	0	1	14.8	0.8	3.6	28.5	4.8	0	0	0	28.7	82.2
1935	0	15	0	38.6	114.2	15.8	0.5	3.8	3.6	0	2.3	3	196.8
1936	7.9	0	26.2	118.6	1.5	116.4	27.8	0.5	5.6	10.2	0.5	25.7	340.9
1937	7.6	0	3.9	50.2	21.3	20.6	6.1	6.1	1.8	0	68.3	0	185.9
1938	0	0	9.2	7.2	54.9	44.5	57.4	7.9	0.8	0	0	24.6	206.5
1939	3.6	0	0	0	0	0	15.8	5.1	0	0	4.6	0	29.1
1940	1	19.8	23.4	9.2	3.3	0	0	0	0	0	0	0	56.7
1941	0	0	39.4	50	30.9	0	0	0	0	0	39.9	8.9	169.1
1942	0	0	107.8	21.9	52	1.3	0	15.5	0	0	0	11.4	209.9
1943	2.5	4.1	0	17	9.9	18.3	0	33	0	0	0	0	84.8
1944	0	0.8	5.4	17.6	10.4	0	17.3	0	0.5	14.7	9.7	6.3	82.7
1945	1.3	0	0	0	44.9	15.8	8.1	31	57.4	84.6	9.1	7.1	259.3
1946	0	0	1.1	11.9	1.3	1.3	4.1	23.7	0	16	0.5	3.8	63.7
1947	0	13.5	1.3	123	5.1	2.9	37.9	53.3	0	11.7	4.1	4.1	256.9
1948	0	0	23.1	17.8	94.8	0	6.9	8.6	0	12	7.6	0	170.8
1949	0	4.1	0	45	2.8	6.1	2.8	3.5	0	0	0.8	11.4	76.5
1950	0	0	81.4	39.1	0	0.5	6.9	0	0	15.2	0	0	143.1
1951	1	0	23.2	69.4	0.5	1.8	31.7	0	0.5	0	17.7	37.6	183.4
1952	0	5.6	1.5	119.7	22.1	0	2.8	1	0.5	0.5	0	0	153.7
1953	0	0	32.8	37.6	0.5	0	5.6	0	0	21.4	21.2	11.9	131
1954	0	0	0.5	39.8	49	6.6	15.7	2.8	4.6	2	0.5	6.4	127.9
1955	17.6	3.6	2.1	8.1	0.5	0	0	63.1	3.8	0	43.2	21.3	163.3
1956	54.1	1.3	9.4	7.3	0	5.1	10.9	0	2.8	1	0	3	94.9
1959			149.2	42	62	0	1.8	3		0	9.2	1.8	269
1960	28.7	0.3	26	46.8		0	14	0	0	0	6.4	0	122.2
1961	0	0.5	5	34.8	2.8	16.2	15.3	30	0	88.7	107.4	197.7	498.4
1962	7.9	0	23.4	18.5	107	0.8	4.6	1.6	0	5.9	32.8	0	202.5
1963	0.5	17.6	4.8	39.9	1.3	0	1.1	60.9	0	1.6	70.4	15.8	213.9
1964	13	22.2	20.8	17.4	0	6.6	4.3	8.6	0	0	0	72.2	165.1
1965	0.3	17.9	50.4	101.8	0	0	0	0	0	0.7	13.1	0	184.2
1966	0	41.6	19.9	121.3	0	0	0.5	51.9	0.4	11.4	15.3	0	262.3
1967	0	1.5	13	185.7	35.1	4.3	132.1	0	0	5.8	104.1	0	481.6
1968	0	28.4	28.5	144.6	0.4	3.7	0	0	0	0	0	18.3	223.9
1969	53.2	17.9	43.5	0.4	45.8	0	0	0	0.7	39.2	7.3	0	208
1970	74.4	0	10.1	54.5	41.6	0	0.9	0.4	0	0	0.8	0	182.7
1971	15.4	0	0.7	47.1	5.8	10.6	1	0	0	0.7	0.6	0.6	82.5
1972	0	33.8	0.4	48.2	0.9	7.1	0	0	9.5	52.9	53.4	0.1	206.3
1973	0.1	0.1	0	6	56.5	9.3	54.9	2.4	36.9	3.5	42.3	0	212
1974	0.7	0.3	94.8	53.4	22	0	90.2	28.7	0	0	0	0.2	290.3
1975	0.2	0	17.4	75.3	38.6	40.7	108.2	1.7	0.2	4.3	0	0	286.6
1976	7.3	2.7	4.6	17.4	14.6	26.3	76.3	0	1.6	0	1.9	4	156.7
1977	43.3	11.7	0.8	161.5	17.2	0	8.2	0.5	0.3	67.9	149.7		461.1
1978	1.5	30.6	39.5		1.9	0	12.5	0	7.2	4.4	3.3	1.4	102.3
1979	11.2	8.3	32.5	61.3	76.5		0	4.4	1.4	0	34.5	4.1	234.2
1980	0.8	0	1.4		32.9	0	0	0	0	0.3	20	0	55.4
1981	0	0	43.6	13.6	1.7	0	0	1.8	0	0.6	0	0	61.3
1982	0	30.5	32.6	29	16.6	0	0.7	0	1.2	5.6	164.6	70.7	351.5
1983	0	15.2	0	1.9	5.2	0	14.9	25.6	22.8	1.5	1.8	17.7	106.6
1984	8.5	0	4	25.2	0	0	0.8	0	0		1.7	11.5	51.7
1985	20.2	0.7	32.8	71.4	68.6	0	5.7	0	0	0	3.1	0	202.5
1986	0	3.9	41.5	79.9	1.5	23.5	0	1.4	0	0	1.7	4.3	157.7
1987	0.8	0	0	79.4	38.4	40.4	0	0	0	0	22.4	0	181.4
1988	2.7	0	0.5	87	6.1	1.5	73.2	48	71.4	8.5	0.3	2.4	301.6
1989	0	19.6	48	8.1	70.7	0	29	0	39.4	0	6.3	47.4	268.5
1990	1.1	21.2	13.6	18	4.1	0	0		0	15.8	0	6.2	80
1991	14.2	0.4	46.2	8.3	38.5	0	4.9	8.6	0	8.8	1.1	2	133
1992	0	3.6	14.4	16.8	10.6	0.8	0	0.4	0	2.9	6.1	2	57.6
1993	9	8.9	2.6	0.5	77.3	10.4	0	0	0	0	4	0	112.7
1994	0	1	18.9	50.8	7.5	1.4	4.5	10.7	0	8.5	27.6	0.4	131.3
1995	0	6.3	9.1	27.3	0	2.8	2.3	1.4	19.4	1.6	0	3.1	73.3
1996	6.1	1.9	35.9	23.3	19.2	52.7	45.5	0	0	0	13.5	0	198.1
1997	0	0	2	123.3	0.4	0	36.1	37	0	30	139.6	5.5	373.9
1998	13.1	5.3	2.3	13.4	20.8	41.6	1.2	26.6	0	0	0.6	0	124.9
1999	0	0	43.4	27.4	5.6	0	13.3	0	0	0.7	4.1	9.2	103.7
2000	0	0	0	9.5	0	0	3.7	0	0	41.9	4.8	16	75.9
2001	23.5	3.1	34.4	6.6	0	0	20.2	2.5	1.2	5.1	2.1	1	99.7
2002	10	0	87.8	56.6	130.6	1.6	0	0	0	19.4	5.4	20.2	331.6
2003	0	0	79.7	61.8	38.6	0	0	13.4	0	0	0	4.8	198.3
2004	58.9	0	4	66.2	13.2	0	0	0	26.2	1.2	39.8	4.4	213.9
2005	0.6	0	17.4	7.8	0	5.2	31.6	0	28.9	0	2.3	0	93.8
2006	1.1	4.3	34.5	36.5	1.2	0	5.1	27.1	0.2	46.2	154.1	57.7	368
2007	0	29.2	18.7	92.9	53.4	0	29.4	52.4	16.4	0	3.5	0.5	296.4
2008	1	0	39	9.8	0.8	0	0	0	5.1	42.2	31.2	0	129.1
2009	4.6	0	0	1.4	30	0	0	0	0	1	2.8	106.1	145.9
	6.702469	6.006173	21.1561	42.6475	23.01375	7.10125	15.42099	9.03875	5.03875	9.1575	19.2642	12.4925	177.0399