HYDROLOGY FINAL REPORT ON GONDORO SMALL SCALE IRRIGATION PROJECT

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Abstract: Despite the huge potential of the area, existing traditional farming practice is not in harmony with the needs and requirements of developing a productive and sustainable agriculture in Ethiopia. The food security situation has continued to deteriorate because of various factors including shortage of rain fall, high population growth, deforestation, soil degradation, pest out break and other related factors are threatening food security situation of the area. Although the initiation of farmer's traditional spate irrigation practice is appreciated, it is not in a position to provide sustainable supply source and effective utilization of water. Therefore, the development of Gondoro SSIP diversion irrigation is expected to contribute towards alleviating these problems thereby increasing food supply and income source to the community and also at local and regional levels.

This work on Gondoro small scale irrigation project consists of genuine work on the design of hydrology for the irrigation scheme for 80 hectares of land, which will be effectual through diversion of Gondoro River. This study includes back ground information and hydrologic design of the project within brief introduction. Hydrologic design is important for safety, economy and proper functioning of hydraulic structures. The proposed of hydrologic design is to estimate maximum, average or minimum flood which the structure is expected to handle. This estimate has to be made quite accurately in order that the project can function properly.

Hydrological analysis has been conducted based on 23 years maximum daily rainfall data. The frequency analysis has been carried out by different statistical distributions methods. The most commonly distributions used to fit extreme rainfall events are: 2 parameter log normal, 3 parameter

log normal, Pearson type III, log Pearson type III and Gumbel's extreme value type I. All the candidate distributions has been tested by three different types of goodness of fit tests that give almost identical statically correlation coefficients. However, the standard Chi-squared errors and Kolmogorov Smirnov errors are significantly lower for the general extreme value distribution. Hence, this distribution has been selected as the best fit for this study.
There is no gauging station on the Gondoro River or nearby river of similar catchment characteristics. Thus, it is preferred to base the flood analysis on rainfall data, which are better both in quantity and quality of data. The Gondoro river base flow was measured by using the floating method since the flow is very small to utilize other methods. In general, three types of estimating flood magnitudes (namely: the rational method, SCS method and gauged data method) can be applied for ungauged catchments. Since, the catchment area of Gondoro diversion scheme is 10.5km^2, the SCS method is preferred. The SCS hydrograph method is selected for the analysis of the rainfall runoff hydrograph and computation of the design flood. The design discharge for the diversion weir corresponding to a return period of 50 years comes out as 33.5m^3/s.

Key words: Hydrology, Gondoro SSIP, Frequency analysis, SCS Method, Design Discharge

1. Introduction

Ethiopia is situated in the horn of Africa, and is bordered by Sudan, Kenya, Somalia, Djibouti and Eritrea. The surface area is more than one million square kilometers and the country stretches from latitude 3° North to latitude 15° North of the equator and from 33° East to 48° East longitudes (MoWR, 2004). It has a large population of approximately 77.1 million people with an annual growth rate of 2.4% (FAO, 2008). The country has nine regional governments, Tigray, Afar, Amhara, Oromia, Somalia, Benshangul-Gumuz, Southern Nations Nationalities and Peoples, Gambella, Harari and two city states Addis Ababa and Dire Dawa. Ethiopia belongs to one of the poorest African countries, with 52% of the population living below the national poverty line (MoWR, 2004) and 31.3% of the population living below US$1 a day (World Bank in Teshome, 2003 p.24).

Eighty-five percent of the population of Ethiopia depends directly on agriculture for their livelihoods, while many others depend on agriculture-related cottage industries such as textiles, leather, and food oil processing. Agriculture contributes up to 50 percent of gross domestic product (GDP) and up to 90 percent of foreign exchange earnings through exports (Davis *et al.*, 2009). It is widely believed that Ethiopia has ample resources for agriculture. The country has 111.5 million hectares of land. While74 million hectares are arable, only 13 million hectares are currently being used for agricultural activities (Abate, 2007).Water resources are also plentiful in many parts of the country. Referring to the 2007 Housing and Population Census of Ethiopia Abate (2007) pointed out that there were about 12 million farm households providing human resources for agriculture and related activities. Ethiopia's livestock resources are among the top in the world, at least in terms of quantity. The country also has a high level of biodiversity, with several different economically important crops indigenous to the country.

In spite of these economically important resources, many challenges confront policymakers and other agents of change. These include the growing demand for food and agricultural products to feed nearly 80 million people, the growing income gap between urban and rural areas, dwindling natural resources, and poverty and food insecurity. It is important to note that some 3.2 million people required emergency assistance in 2014 (FAO, 2014).

According to the World Bank, the agricultural sector is the leading sector in the Ethiopian economy, 47.7 percent of the total GDP, as compared to 13.3 percent from industry and 39 percent from services (Awulachew et al, 2007 p.1). More than 85% of the total labour force is working in the agricultural sector (CSA in Awulachew et al, 2007 p.1). To improve these livelihoods, the International Fund for Agricultural Development (IFAD) contributes with technical assistance and financial support. IFAD's strategy in Ethiopia focuses on; "supporting investment programmes with the greatest potential impact on sustainable household food security and on the incomes of rural poor people, particularly small-scale farmers and herders, and women in all categories" (IFAD, 2008). Means to help improve the production and income of farmers can be irrigation. In fact, irrigation can improve yields significantly and even double them as indicated by farmers from the Wadi Laba spate irrigation system in Eritrea (Haile, 2007).

Fortunately, Ethiopia is lucky in that it has got ample source of surface and subsurface water for which it is known as "The Water Tower of East Africa." Moreover; the irrigation potential is estimated to be about 4.25 million hectare of which only 5.8% is irrigated.(source: Study carried out by International Water Management Institute-IWMI). Nowadays, implementation of small and medium scale irrigation schemes is being given priority in the water sector development strategy of Ethiopia. Therefore, the development of Gondoro Small scale irrigation project (SSIP) whose design report included in this study is one of the scheme expected to contribute towards alleviating food problems thereby increasing food supply and income source to the community and also at local and regional levels.

The aim of this paper is to estimate hydrologic design parameters for the proposed Gondoro SSIP diversion weir. Most importantly the following evaluations will be carried out. (1) Time series data analysis of the monthly rainfall, (2) Catchment features pertinent to the analysis and simulation of hydrological data, (3) Temperature (length of records, maximum, minimum, average values) analysis, (4) Any other climate data features of importance ad indicate the effects on the irrigation scheme, (5) Rainfall (length of records, monthly distribution and its intensity, average values) data collection and analysis, (6) Project design floods estimation, (7) Estimation of monthly potential Evapo-transpiration and rainfall deficit, (8) Estimation of incoming floods to the diversion and the outflow design flood and (9) Estimation dependable and availability of lean flow of river flow to schemes to irrigate the proposed land. Therefore, the main objective of this paper is to present a simple and unified framework along with examples and applications so that it can be accessible to a broader audience in the field.

1. Study Area

The Gondoro diversion project is located in the Omo-Gibe basin which is found in the southern part of Ethiopia. The area has high potential water and land suitable for irrigation development. The average altitude of the watershed of the diversion site is 2132meters above sea level (masl) whereas the average elevation of the command area is 1900m. The entire watershed lies in Adiyo Woreda. The command area also lies within this woreda. The small scale irrigation project is anticipated by diverting water from Gondoro Stream which is a tributary of Gojeb River that eventually drains to the Omo-Gibe River. The catchment area of the Gondoro watershed at the diversion site is 10.5 km^2. The maximum length of the river up to the diversion site is about 9.6km. The elevation of the river center at the diversion site is 2132 meter a.m.s.l.

The nearest climatic station is Bonga meteorological station. The average altitude of the project area is similar to the altitude of Bonga. Hence, the mean, maximum, and minimum annual temperatures of the project area are 19.7, 27.4, and 11.5^oC respectively. Maximum temperatures occur in the months February-May and minimum temperatures June - September. Monthly wind speed variation is from 0.8 - 2.1 m/sec; the yearly average is only 0.9 m/sec. The maximum sunshine hours duration of 8.0 hours occurs in December where as the minimum of 3.1 hours occurs in July. Relative humidity is the maximum in July, August & September. The yearly average is 74%. The average annual rainfall over the command area is about 1650mm.

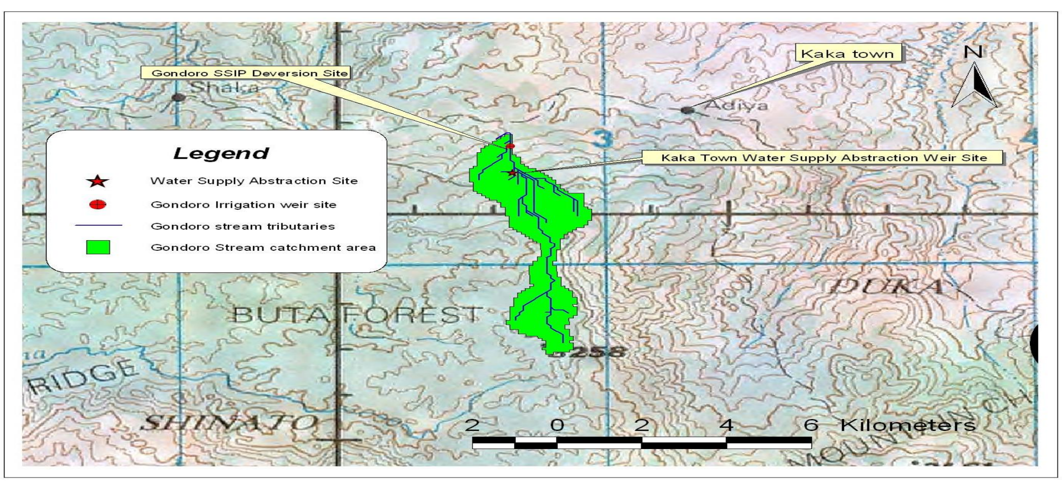

Figure 1 Locations of Weir sites on Gondoro Stream

1.1 Data collection

Hydrological data are essential in the design of the diversion weir, main canal, intake head works, flood protection works and irrigation system. Some of the relevant parameters required at project locations are minimum flow, the mean and maximum flows of the river, the sizing of the weir and catchment characteristics. This study used key informant interviews with community representatives. Secondary data are collected from government offices, National Meteorological Service Agency and Central Statistical Agency. Climatic data were obtained from Bonga branch of the National Meteorological Service Agency. Data obtained from various sources were analyzed using descriptive statistical analysis.

1.2 Rainfall patterns

The rainfall is highly variable both in amount and distribution across regions and seasons (Tesfaye, 2003, Tilahun, 1999; Mersha, 1999). The seasonal and annual rainfall variations are results of the macro-scale pressure systems and monsoon flows which are related to the changes in the pressure systems (Haile, 1986; Beltrando and Camberlin, 1993; NMSA, 1996). The most important weather systems that cause rain over Ethiopia include Sub-Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and Somalia Jet (NMSA, 1996). The spatial variation of the rainfall is, thus, influenced by the changes in the intensity, position, and direction of movement of these rain-producing systems over the country (Taddesse, 2000). Moreover, the spatial distribution of rainfall in Ethiopia is significantly influenced by topography (NMSA, 1996; Camberlin, 1997; Taddesse, 2000), which also has many abrupt changes in the Rift Valley.

The annual maximum rainfall data record extending between 1985 to 2007 is analyzed. Out of the total 288 monthly records, there are only 3 months (less than 1%) missing data. The data source is the National Meteorological Services Agency (NMSA). The missing monthly data can be filled using statistical techniques. However, only the recorded data has been used to determine the dependable rainfall. The average annual rainfall at Bonga Station is about 1799 mm. The variability of annual rainfall as explained by coefficient of variation is about 11 %.

The average annual rainfall over the command area is about 1650mm (as seen in the isoheytal map, Fig. 3.2), where as that of Bonga station is 1799mm. Hence, the monthly rainfall values of Bonga are adjusted by a factor of F = 1650/1799 = 0.92 to arrive at the mean monthly and dependable rainfall values for the command area. The monthly rainfall distribution as shown in Figure 3.2 has uni-modal characteristics with better rainfall distribution from May to September. Rainfall over the watershed is mono-modal; nearly 80 % of the annual rainfall occurs from March to October

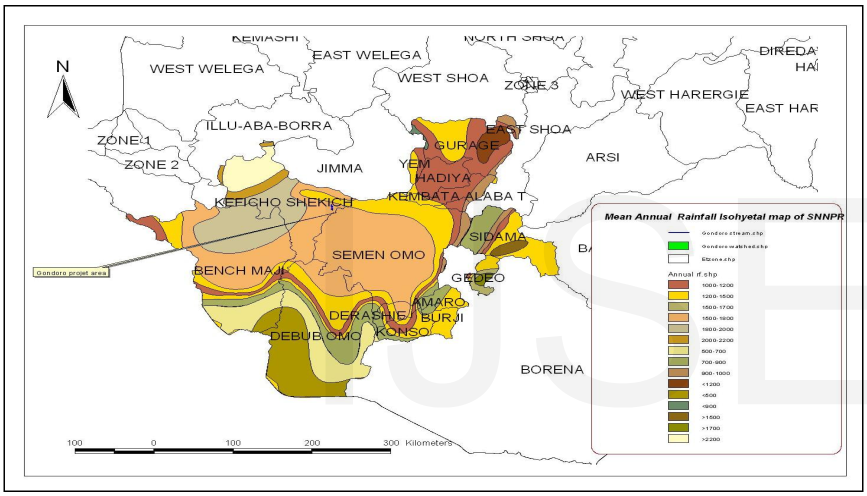

Figure 2 Gondoro Catchment & Isohyets of Annual Rainfall Map

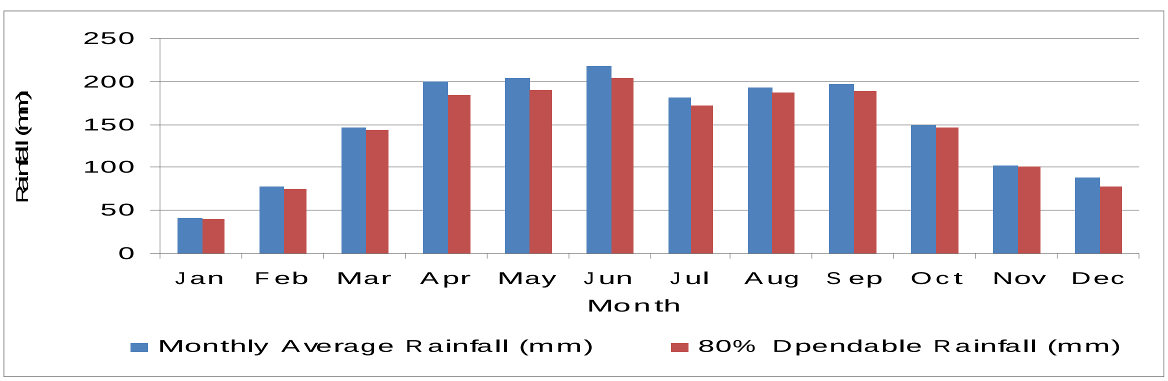

Figure 3 Average and 80% dependable rainfall for the project area

Table 1 Monthly Rainfall and Rainfall coefficients

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
mean	41	78	146	199	204	218	182	194	197	150	102	88	1799.0
80% monthly dep. R.F.	39.2	74.0	143.6	184.7	190.5	204.0	171.6	188.1	189.6	145.6	100.4	78.3	
Coeff. Of Correlation	1.0	0.9	1.0	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	0.9	
RC (mean)	0.4	0.7	1.3	1.7	1.8	1.9	1.6	1.7	1.7	1.3	0.9	0.8	

Accordingly, March to October represent big rainfall with moderate concentration whereas months with Small of rainfall are in November and February. There is one dry month which is in January with RC of less than 0.6.

Irrigation by stream diversion is required if crop production is envisaged in the long period of October to March.

2. Result and Discussion

2.1 Estimation of Potential Evapo-Transpiration (PET)

Evapotranspiration has a significant role in irrigation scheduling and water resources management. The highest precision of evapotranspiration could be obtained using lysimeter (Banihabib et al. 2012; Schrader et al. 2013; Xu and Chen 2005) or imaging techniques (Rahimi et al. 2014; Tian et al. 2012, 2013; Valipor et al. 2014), but their costs are too high. Instead, researchers can use the crop coefficients and reference evapotranspiration to calculate the actual evapotranspiration. Thus, the Food and Agriculture Organization of the United Nations (FAO) Penman-Monteith method (Allen et al. 1998) has been presented to estimate the potential evapotranspiration. Although the FAO Penman-Monteith (FPM) has been applied in various regions of the world (Estevez et al. 2009; Valipour 2012a, b, c, d, e, f, g, h, I, j, 2014m, n; Valipour et al. 2013a, b, c, 2012a, b, c, d), it needs too many parameters to estimate the potential evapotranspiration. For this study, PET is calculated by the Penman-Monteith method using FAO CROPWAT version 4.3 programs. The input data are Maximum & Minimum

Temperature, Relative Humidity, Wind Speed, and Sunshine duration. The results, on monthly basis, are shown in Table 3.1 and 3.2. The average annual PET of the project area is 1217 mm.

Table 2 Output of CROPWAT 4.3 for the Project Area

Country :	Ethiopia			Station: Bonga			
Altitude:	2000 meter(s) a.m.s.l.						
Latitude: 7.3 Deg. (North)				Longitude: 36.5 Deg. (East)			
Month	MaxTemp	MiniTemp	Humidity	Wind Spd.	SunShine	Solar Rad.	ETo
	(deg.C)	(deg.C)	(%)	(Km/d)	(Hours)	(MJ/m2/d)	(mm/d)
Jan.	29	10	66	95	7.6	11	1.95
Feb.	29.7	11	69	103.7	6.6	12.4	2.6
Mar.	29.2	11.9	56	181.4	6.4	15.1	4.07
Apr.	28.1	12.7	71	129.6	6.6	17.9	3.97
May	27	12	75	112.3	6	18.6	3.99
Jun.	25.9	12.4	80	103.7	4.9	17.5	3.69
Jul.	24.3	12.4	85	95	3.1	14.6	3.05
Aug.	24.6	12.4	85	103.7	3.6	14.3	2.95
Sept.	25.8	11.7	4.9	86.4	4.9	14.1	3.34
Oct.	27.8	11	80	95	6.8	13.6	2.57
Nov.	28.1	10.3	73	77.8	7.6	11.6	1.86
Dec.	28.4	10.3	64	69.1	8	10.5	1.46
Average	27.3	11.5	67.4	104.4	6	14.3	2.96

Table 3 Monthly PET at the Project Area (mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Total
118	109	136	123	114	.7 99	90	96	99	115	108	109	1217

2.2 Rainfall Frequency Analysis

There is no gauging station on the Gondoro River or nearby river of similar catchment characteristics. Thus, it is preferred to base the flood analysis on rainfall data, which are better both in quantity and quality of data. The SCS hydrograph method is selected for the analysis of the rainfall runoff hydrograph and computation of the design flood.

2.2.1 Annual Highest Daily Rainfall Series

Data from Bonga Meteorological station has been used for determination of design rainfall. Frequency analysis of the annual maximum daily rainfall has been carried out to compute design 24-hour rainfall of various return periods. The maximum annual daily rainfall series for 1985-2007 periods has been used for the analysis.

Table 4 Annual Maximum Daily Rainfall at Bonga Station

Year of Record	RF (mm)
1985	46.6
1986	52
1987	46.7
1988	62.5
1989	40
1990	70
1991	70.3
1992	36.1
1993	44.5
1994	54.3
1995	40.1
1996	70
1997	70.5
1998	55
1999	50.8
2000	44.5
2001	54.5
2002	40
2003	47
2004	50.3
2005	38
2006	45.6
2007	40
Average	50.8
St. Dev.	11.1
CV (%)	21.7

2.2.2 Tests for Outliers

Outliers are data points which depart significantly from the trend of the remaining data. The observed annual daily maximum rainfall series was subjected to tests for high and low outliers. This test is conducted using the methodology specified in the US Army Corpse of Engineers Manual on Hydrologic Frequency Analysis.

The following equation is used for detecting low and high outliers:

$$X_H = \bar{X} \pm K_N S \qquad (1)$$

where,

X_H is low/high outlier threshold in log units

$\bar{X}$ mean logarithmic of the test series

S is standard deviation of the series

K_N is outlier test value for a given sample size & level of significance

For the Log-formed series of Table 3.5:

$\bar{X}$ = 1.697 and S = 0.091; and K_N = 2.448 for N = 23 and 10% level of significance

X_H = 1.697 ± 2.448 * 0.091

X_H (Low) = 1.474 and, X_H (High) = 1.920

Lower Limit of low outlier = 10 ^ 1.474 = 29.8mm
Upper Limit of high outlier = 10 ^ 1.920= 83.1 mm

Hence, the upper limit for high outliers is computed using the above equation as 83 mm and the lower limit for low outliers becomes 30 mm. Therefore, the data series has no outliers and all the data series will be used for the frequency analysis.

2.2.3 Selection of Distribution

The observed data was tested using different statistical distributions. The most commonly distributions used to fit extreme rainfall events are: 2 Parameter Log Normal, 3 Parameter Log Normal, Pearson Type III, Log Pearson Type III and Gumbel's Extreme Value Type I.

Table 5 Frequency Analysis of Annual Maximum Daily Rainfall

Return Period (Yrs)	2 Par log normal	3 Par log normal	Pearson Type III	Log Pearson Type III	EV I
200	86.42	86.07	89.47	85.76	95.92
100	81.91	81.65	84.25	81.31	89.34
50	77.25	77.08	78.89	76.72	82.74
25	72.38	72.29	73.35	71.92	76.09
10	65.43	65.43	65.6	65.11	67.12
5	59.53	59.57	59.18	59.32	60.03
Correl Coeff.	0.9309	0.9305	0.934	0.927	0.940

Goodness of Fit - Summary

No	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Gen. Extreme Value	0.108	1	0.378	3	0.152	1
2	Log-Pearson 3	0.113	2	0.412	4	0.162	2
3	Lognormal	0.132	6	0.592	6	1.52	3
4	Lognormal (3P)	0.123	4	0.365	1	1.97	6
5	Pearson Type III	0.122	3	0.518	5	1.57	4

All the candidate distributions has been tested by three different types of goodness of fit tests that give almost identical statically correlation coefficients. However, the standard Chi-Squared errors and Kolmogorov Smirnov error are significantly lower for the General extreme value distribution. Hence, this distribution has been selected as the best fit for this study.

2.2.4 Temporal distribution of the 24-hour Areal Rainfall

Because there is no information of the rainfall hourly distribution for the project site the design daily storm is hourly distributed by using the following equation:

$$P = M^* \sqrt{T} \qquad (2)$$

Where P is rainfall depth, T is rainfall duration and M is a constant. Using the known/computed M value for the daily rainfall, the next step was to determine the accumulated rainfall value for each hour at the time of the 24 hr rainfall occurrence, by using the appropriate M value and the required T. Taking the differences between adjacent hours it was possible to obtain the hourly rainfall distribution. The final step was to arrange the hourly series for each 24-hour rainfall by using the Alternating Block Method (Chow et al, 1988). Table 3.5 presents an example of the hourly distribution of the 24 hours 50yr return period rainfall. Similar procedure was performed to obtain the hourly distribution for any other design rainfall, such as the 10, 25 and 100 years return period rainfall events.

Table 6 Hourly Distribution of Design rainfall

Use the Alternating block method			Ret. Period = 50 Years	
P = M * Sqrt (T)		24 Hr. Point Rainfall=	82.74mm	
M =82.74/sqrt(24) = 16.9		Catch Area=	10.5 km^2	
T (hr)	Point Cumulative Rainfall, mm	Areal Cumulative Rainfall, mm	Areal Incremental Rainfall (mm)	Alternating Block,mm
1	16.9	15.8	15.8	1.7
2	23.9	22.7	6.9	1.8
3	29.3	27.9	5.3	1.9
4	33.8	32.4	4.5	2
5	37.8	36.3	3.9	2.1
6	41.4	39.9	3.6	2.3
7	44.7	43.2	3.3	2.5
8	47.8	46.2	3.1	2.7
9	50.7	49.1	2.9	3.1
10	53.4	51.8	2.7	3.6
11	56.0	54.4	2.6	4.5
12	58.5	56.8	2.5	6.9
13	60.9	59.2	2.4	15.8
14	63.2	61.5	2.3	5.3
15	65.4	63.7	2.2	3.9
16	67.6	65.8	2.1	3.3
17	69.6	67.9	2.1	2.9
18	71.7	69.9	2.0	2.6
19	73.6	71.8	1.9	2.4
20	75.5	73.7	1.9	2.2
21	77.4	75.6	1.9	2.1
22	79.2	77.4	1.8	1.9
23	81.0	79.1	1.8	1.9
24	82.7	80.9	1.7	1.8
Sum			80.9	80.9

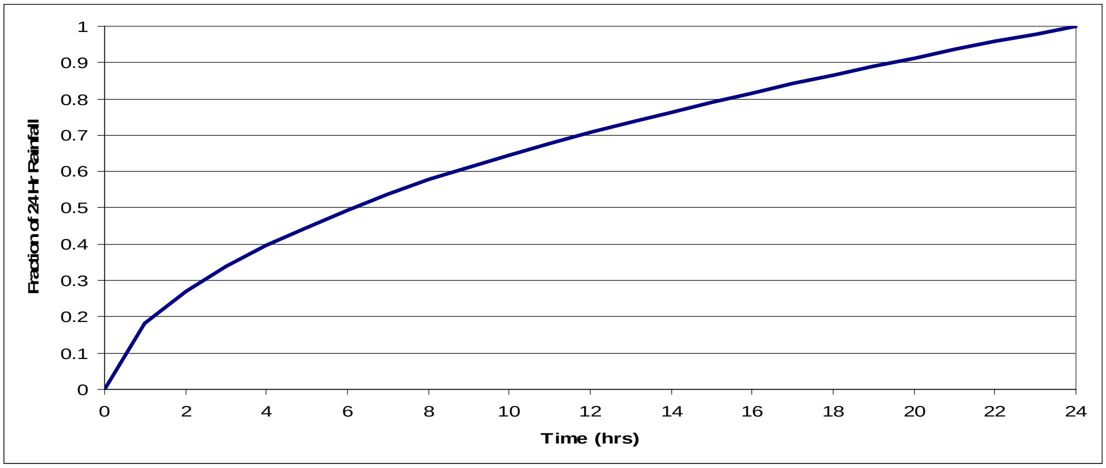

Figure 4 Design Rainfall Distribution Curve

2.3 Estimation of design discharge

In general, three types of estimating flood magnitudes (namely: the Rational Method, SCS method and Gauged Data method) can be applied for ungauged catchments. Since, the catchment area of Gondoro diversion scheme is 10.5 km2, The US Soil Conservation Services (SCS) Method is preferred.

2.3.1 Estimation of Excess Runoff

A relationship between accumulated rainfall and accumulated runoff was derived by SCS (Soil Conservation Service). The SCS runoff equation is therefore a method of estimating direct runoff from 24-hour or 1-day storm rainfall. The equation is:

$$Q = (P - Ia)^2 / (P - Ia + S) \quad (3a)$$

where

- Q = accumulated direct runoff, mm
- P = accumulated rainfall (potential maximum runoff), mm
- Ia = initial abstraction including surface storage, inception, and infiltration prior to runoff, mm
- S = potential maximum retention, mm

The relationship between Ia and S was developed from experimental catchment area data. It removes the necessity for estimating Ia for common usage. The empirical relationship used in the SCS runoff equation is:

$$Ia = 0.2S \quad (3b)$$

Substituting 0.2S for Ia in equation, the the SCS rainfall-runoff equation becomes:

$$Q = (P - 0.2S)^2 / (P+0.8S) \quad (3c)$$

S is related to soil and land cover conditions of the catchment area through CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = 254x[(100/CN) - 1] \quad (3d)$$

Conversion from average antecedent moisture conditions to *wet* conditions can be done by using tables or multiplying the average CN values by Cf [where Cf = $(CN/100)^{-0.4}$]

Convoluting Excess Runoff using the SCS Unit Hydrograph

At the heart of the SCS UH model is a dimensionless, single-peaked UH. This dimensionless UH expresses the UH discharge, qt, as a ratio to the UH peak discharge, qp, for any time t, a fraction of Tp, the time to UH peak.

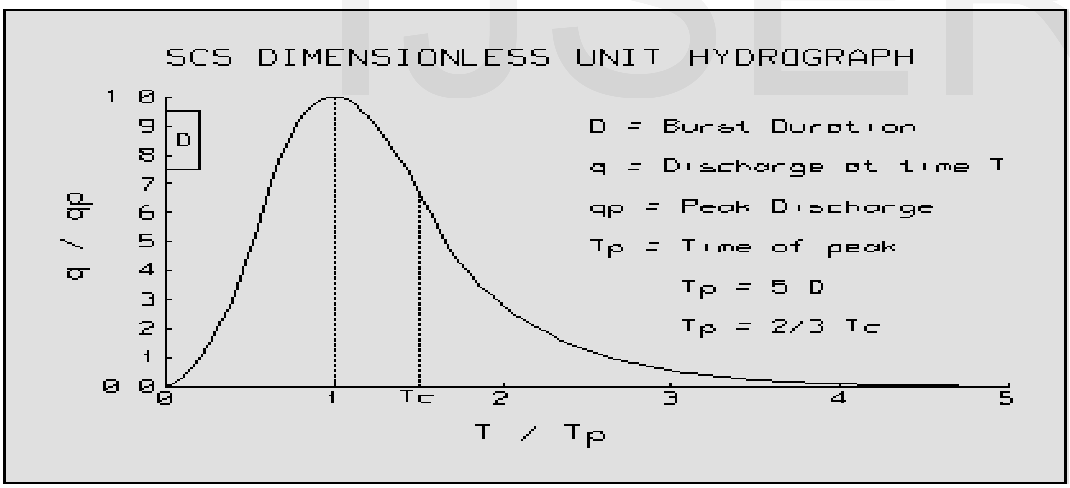

Figure 5 SCS dimensionless unit hydrograph

Research by the SCS suggests that the UH peak and time of UH peak are related by:

$$q_P = C^* A/Tp \quad (4a)$$

in which A = watershed area (km^2); and C = conversion constant (2.08 in SI system). The time of peak (also known as the time of rise) is related to the unit excess precipitation duration as:

$$Tp = D/2 + t\ lag \quad (4b)$$

in which D = the excess precipitation duration (which is also the computational interval); and tlag = the basin lag, defined as the time difference between the center of mass of rainfall excess and the peak of the UH. For adequate definition of the ordinates on the rising limb of the SCS UH, a computational interval, D , that is less than 29% of tlag shall be selected (USACE, 1998a). With this, the SCS UH becomes a one parameter model which requires tlag as input.

2.3.2 Estimating the Model Parameter

The SCS UH lag can be estimated via calibration for gauged headwater sub watersheds. For ungauged watersheds, the SCS suggests that the UH lag time may be related to time of concentration, tc, as:

$$t_{lag} = 0.6\ tc \qquad (4c)$$

A most commonly used empirical equation for the estimation of tc is that of Kirpich given as:

$$Tc = (1/3080) \times L^{1.155} .\ H^{-0.385} \quad \text{(Kirpich equation)} \qquad (5a)$$

where

Tc = time of concentration (in hours),

L = maximum length of main stream (in meters),

H = elevation difference of upper and outlet of catchment, (in meters).

2.3.3 Determination of Curve Number

The curve number (CN) for the watershed is determined from the land use/land cover and soil data of the watershed. Secondary data from GIS sources (Ethio_GIS and Woody Biomass) was used to extract the required information for the watershed.

The soil type of the watershed is dominated by Orthic Acrisols (68%), and Dystric Cambisols (32%). These soils belong to Hydrologic Soil Group B of the SCS. They are characterized as Silt loam, or loam having a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Table 7 Soil Type of Gondoro Watershed

Soil Type	Area Coverage (km^2)	Hydrologic Group
Orthic Acrisols	7.14	B
Dystric Cambisols	3.36	B
Total Area	10.5	

With regard to landuse, about 10% of the watershed is cultivated land, 80 % is wooden grassland whereas the remaining 10% is covered by forest plantation, alpine forest and shrubland.

For the hydrologic soil group B, the curve numbers for Antecedent Moisture condition II (Average) and AM condition III (Wet) is shown in Table 3.9 below. ERA manual (2003) recommends using the CN for antecedent moisture condition II (average) for the region where the project site is located. However, considering the importance of the structure the higher CN of AMC III has been adopted in this study.

Table 8 Land use data and Curve Number Estimation

Land use	Area Coverage (Km^2)	% Coverage	CN – AMC II
Cultivated Land	1.05	10	79
Wooden Grassland	9.45	90	76
Total	10.5	100.0	
Weighted CN AMC II			78.7
Weighted CN AMC III			89.5

3.4.4 Computation of Peak Floods

For the computation of the design flood using the SCS Synthetic Unit Hydrograph method, the catchment and the drainage network above the diversion site has been delineated from the 90m by 90m DEM using SWAT in the GIS. The GIS processing phase includes derivation of the important morphological characteristics that is used to derive the maximum time of flow concentration (tc), such as the longest flow length (*L*), the centroidal flow length (Lc), the average slope.

The time of concentration was computed using the widely applied Kirpich formula shown below.

$$tc = 0.000328 L^{0.77} S^{-0.385} \qquad (5b)$$

Where tc is the time concentration, The maximum length of water travel (m) and S is average slope of the channel given as a fraction of the vertical elevation rise to the corresponding horizontal length.

The time to peak (TP) has been estimated from the tc values using US SCS method. The Probable Maximum Precipitation (PMP) is then transformed into PMF inflow hydrograph at the inlet to the weir site using the standard dimensionless SCS unit hydrograph. Accordingly, floods computed for various return periods are shown in Table 3.11 below. The design hydrograph for 50 year return period is also shown in Figure 3.6.

Table 9 Parameters to Determine Peak Discharge

Description	*Symbol/Abr.*	*Unit*	*Gondoro*
Catchment area	A	km^2	10.5
Minimum catchment elevation	Min Elv	Masl	2132
Maximum catchment elevation	Max Elv	Masl	3258
Length of main stream channel	L	m	9515
Time of concentration	Tc	Hrs	0.88
Curve Number	CN (AMC II) CN (AMCIII)		78.7 89.5
The 1: 50 year maximum 24-hour Areal rainfall	RF24	mm	80.9

Table 10 Computed Flood Discharges for various return periods

	Ordinate of Hydrograph(m3/s)			
Time (hr)	*1:10year*	*1:25 yr*	*1:50 yr*	*1:100 yr*
0	0.0	0.0	0.0	0.0
0.15	0.7	0.6	0.6	0.5
0.3	1.4	1.2	1.1	1.1
0.45	2.2	2.3	2.4	2.4
0.6	4.7	5.6	6.3	6.7
0.75	8.7	11.1	13.0	14.2
0.9	12.7	16.6	19.7	21.7
1.05	19.6	25.3	29.9	32.7
1.20	*22.2*	*28.5*	*33.5*	*36.6*
1.35	20.8	26.6	31.2	34.0
1.6	14.1	18.2	21.3	23.3
1.75	10.5	13.4	15.7	17.1
1.9	6.9	8.7	10.1	11.0
2.05	3.5	4.3	5.0	5.3
2.2	1.0	1.2	1.4	1.5
2.35	0.0	0.0	0.0	0.0

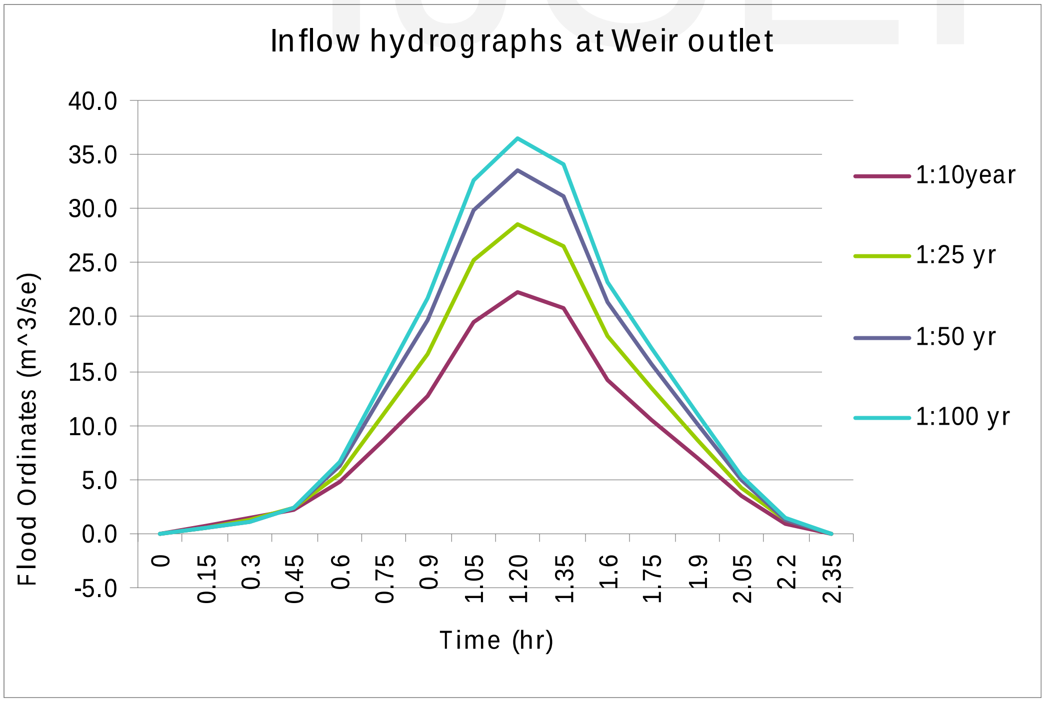

Figure 6 Design Hydrographs for different Years Return Period

Hence, the design discharge for the diversion weir corresponding to a return period of 50 years is $33.5m^3/s$.

Conclusions

Hydrological analysis has been conducted based on 23 years maximum daily rainfall data. The frequency analysis has been carried out by different statistical distributions methods. The most commonly distributions used to fit extreme rainfall events are: 2 parameter log normal, 3 parameter log normal, Pearson type III, log Pearson type III and Gumbel's extreme value type I. All the candidate distributions has been tested by three different types of goodness of fit tests that give almost identical statically correlation coefficients. However, the standard Chi-squared errors and Kolmogorov Smirnov errors are significantly lower for the general extreme value distribution. Hence, this distribution has been selected as the best fit for this study.

There is no gauging station on the Gondoro River or nearby river of similar catchment characteristics. Thus, it is preferred to base the flood analysis on rainfall data, which are better both in quantity and quality of data. The Gondoro river base flow was measured by using the floating method since the flow is very small to utilize other methods. In general, three types of estimating flood magnitudes (namely: the rational method, SCS method and gauged data method) can be applied for ungauged catchments. Since, the catchment area of Gondoro diversion scheme is $10.5km^2$, the SCS method is preferred. The SCS hydrograph method is selected for the analysis of the rainfall runoff hydrograph and computation of the design flood. The design discharge for the diversion weir corresponding to a return period of 50 years comes out as $33.5m^3/s$.

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