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Flood Frequency Analysis in Gelana in Ethiopia

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Abstract: ***The objective of this study was flood frequency analysis in the case of Gelana. The flood frequency analysis result indicates that Performance of the model for both the calibration and validation of the watershed were found to be reasonably good with Nash-Sutcliffe coefficient value of 0.793 and 0.851 respectively. In calibration, the peak discharge that computed at the Outlet is 111.9 m^3/s, that of observed peak discharge is 157 m3/s, the peak discharge that computed at the Outlet is 125.2 m3/s, and that of observed peak discharge is 157 m^3/s in the case of validation.***

Keywords: Gelana, frequency analysis, return period, flood peak, Flood magnitude

1. Introduction

1.1 Background

Extreme events, such as floods are among the catastrophic natural events that cause severe consequences for human society. In many countries of the world, floods are causing damages to properties and agricultural lands that result in huge economic and life losses for the affected areas. For example, in Southern Africa, it is often reported in WebPages such as UN news center. (http://www.un.org/apps/news/story.asp? News November – December 2015) that every country of the region are on alert for potentially disastrous flooding. The UN Office for the Coordination of Humanitarian Affairs (OCHA) in January 27, 2011 warned that floods in Southern Africa could be severe and lead to food shortages. Five countries (such as; Botswana, Mozambique, Namibia, Zambia and Zimbabwe) have also recently forecasted serious flooding phenomenon that could affect tens of thousands of people, and damage infrastructure, crops and homes UNNC (2011),

A common problem encountered in many aspects of water resources engineering is that of estimating the return period of extreme hydrological events like floods, for a site or a group of sites (Cunnane, 1989). A reliable estimation of such extreme flood events is of great significance in minimizing damage by facilitating proper planning and design of civil engineering structures such as dams, culverts, bridges, barrages and other flood control structures. One of the widely used methods of estimating the design flood at a particular site is by performing frequency analysis of observed flood peaks over a number of years at that site.

1.2 Statement of the Problem

In the author of this research long time experience, in Gelana where the study conducted, unexpected huge amount of flooding happened and submerged large area repeatedly. Still no study was conducted specifically on maximum flood recurrence interval to warn and prepare the community across Gelana that could mitigate the problem of flooding. Due to this most of the time the flood results in destructing life and properties of the community. Mostly the occurrence of flood is sudden and due, the people cannot save their properties even life.

The flood submerges houses, destruct properties of Gedeo people at Yirgachefe and Chelelectu, Guji oromia people at Como'lcha, Hidbira, Borre, and Koore people at Barbare, Dorbade and Pachato. At the vulnerable areas the flood close land transport (Amaro – Dilla, Dorbade – Borre), damage agricultural land (at yirgachefe, chelelectu, Como'lcha, Barbare, Dorbade, Pachato, Borre and Malka). All the communities of the affecting areas are almost farmers and they have no alternative way rather than farming. Once agricultural land damage means; loss of crop for a season. That is a great problem to lead their life. The flood also disturbs aesthetic value of the environment. Due, the community is vulnerable to disease, (Ethiopia floods flash update, 2018).

In Ethiopia, totally 210,600 people were affected and 105,300 people were displaced, in Gelana, 5000 people were affected and 2500 people were displaced due to unexpected flooding from November 2015 to January 2016, (OCHA, 2015 – 2016). To mitigate and resolve the problem, this study will analyze the frequency of the flood and maps the vulnerable area.

2. Objectives

2.1 General Objective

The aim of this study was to analyze flood frequency in Gelana Catchment, which may serve as a basic input to aware and preparedness of the community.

2.2 Specific Objectives

- To relate the magnitude of extreme event to its frequency of occurrence.
- To analyze the peak discharge by calibration and validation.
- To estimate the maximum design flood.

3. Literature Review

According to (Robinson, Ward et al. 1990), the precipitation reaching the above ground surface may then collect in order to form surface runoff; it may infiltrate into the ground or back up into the sky as a evaporation. After infiltration of the rainfall into the soil, the flow process becomes unpredictable since the catchment runoff behavior is closely

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related to the subsurface physiographic, geometry and geology.

(Mishra and Singh, 1999) modified SCS-CN method by taking $0.5(p-Ia)$ in place of $(p-Ia)$. The existing SCS-CN method and the proposed modification are compared and the modified version is found to be more accurate than the current version.

(Zhan and Huang 2004); (Seibenhener, Geetha et al., 2007) those researchers integrated the SCS-CN model into the GIS/RS system to extend the model applicability to complex watersheds with high temporal and spatial variability in soil and land use. Moreover, a great number of researchers carried out researches using GIS technique in order to determine curve number and runoff quantity in different regions in the world.

(Fakharinia, Lalehzari et al., 2012) provided curve number map by merging the land usability, soil texture and slope maps in GIS and by the help of SCS table. (Misra and Enge, 2006) employed a large dataset from 84 small watersheds (0.17– 71.99 ha in area) in the USA to investigate a number of Ia - S relationships that incorporated antecedent moisture as a function of antecedent precipitation.

(Panahi, Watson et al., 2013) carry out a scientific investigation and evaluation in order to quantitatively study and predict the runoff resulting from precipitation, and proposed a model for estimating runoff and determining potential sites of runoff production of the study area by using experimental methods. SCS-CN method was utilized, due to its precision and efficiency. By producing CN, runoff potential of the region was determined.

3.1 Review of Frequency analysis

The frequency of floods with various risks of exceedance, are therefore needed for a wide range of engineering problems, planning for weather-related emergencies, reservoir management, pollution control, and insurance risk calculations (Gottschalk and Krasovskaia, 2001; Kjeldsen et al., 2002; Saf, 2008).

Meteorological forecasts can only gives very short forecasts in an accurate form, which may not allow sufficient time to reduce the impact of flood events. In addition, due to previous false alarms, people no longer take flood forecasts seriously (Madamombe, 2005).

Flood frequency may also examine the fitting of a probability model to the sample of annual maximum flood peaks recorded over a period of observation, for a watershed of a given region. The model parameters explained can then be used to predict the extreme events of large recurrence interval (Pegram and Parak, 2004).

4. Material and Method

4.1 Description of Study area

Gelana River originates from Yirgachefe area, Gedeo zone. This watershed is part of the Rift valley Basin that drains in to Lake Abaya which is situated on the South Western side of Lake Abaya. Due to the agro –forestry practice of the Gedeo people, especially the land cover of the upper catchments maintained well. The Gelana watershed is in a better condition in terms of land cover and environmental degradation. Because of better land cover, the flux of the sediment from the watershed would be relatively low.

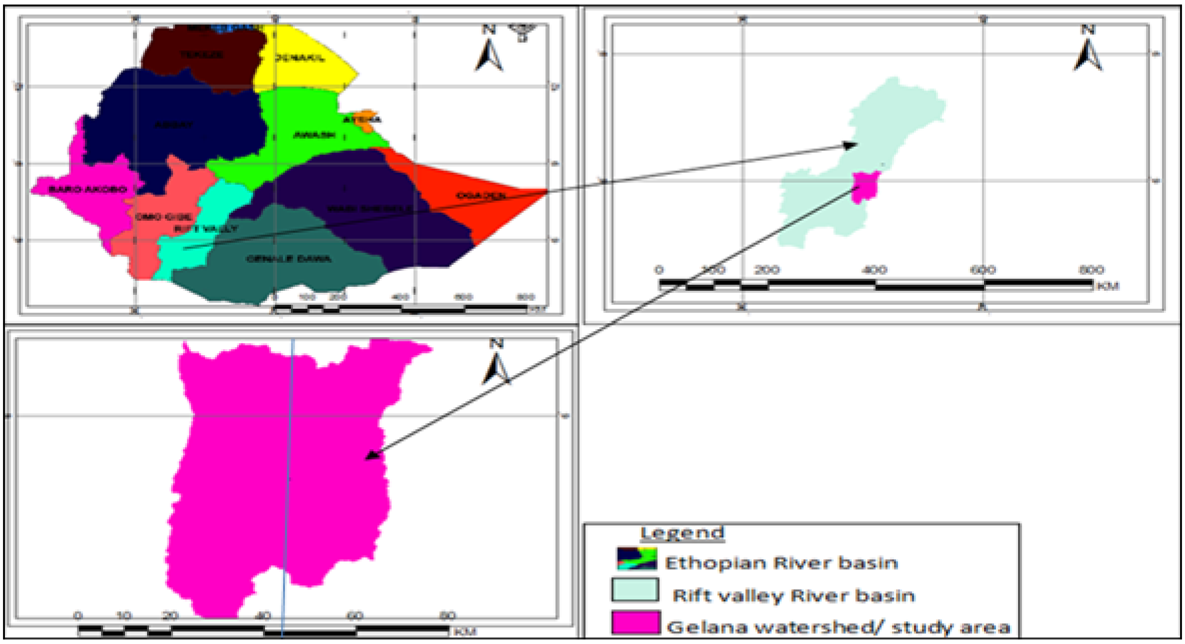

Figure 1: Study area of Gelana watershed

The Gelana River contributes about 10% of the total inflow of Lake Abaya (WWDSE, 2006). Lake Abaya is the final receptor of Gelana watershed flow. It has diverse altitudinal difference which ranges from 1162 m to 3136 meters above mean sea level. The study covers area of 9339.7 Km^2. The figure 2 shows the yearly average precipitation distribution of the gauging stations that usefor this study.

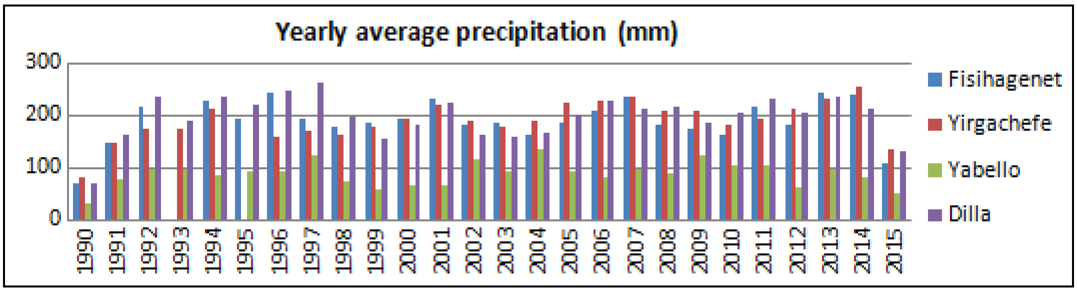

Figure 2: Yearly precipitation distributions

Table 1: Yearly flow data

Year	Gelana flow (m3/s)	Yirgachefe (m3/s)	Yabello (m3/s)	Fsihagenet (m3/s)	Dilla (m3/s)
1986	17.7	18.7	26.5	8.96	8.6
1987	135.3	31	59.2	37.92	16.2
1988	59.375	27	28.3	12.4	13.4
1989	157.2	49.2	61.8	28.8	26.4
1990	140.9	36.3	34.8	32.56	10.2
1991	9.56	7.27	9.77	4.47	6.04
1992	9.56	5.56	7.67	6.41	6.5
1993	33.37	5.8	8.76	4	5.25
1994	26.61	6.11	8.51	8.76	10.54
1995	24.26	6	6.19	7.37	10.75
1996	26.38	2.93	6.76	6.64	7.34
1997	25.25	6.3	10.86	5.54	7.17
1998	24.48	7.68	6.31	6.27	10.91
1999	23.71	9.22	13.38	12.18	10.48
2000	25.93	6.67	4.41	6.96	8.48
2001	26.61	7.76	4.01	11.61	7.17
2002	23.82	6.3	7.79	7.68	8.54
2003	16.61	6.97	7.27	7.11	9.25
2004	25.81	5.78	11.14	7.56	7.37
2005	22.05	7.46	9.35	6.22	7.33
2006	20.28	5.84	5.78	7.45	7.6
2007	21.57	12.93	4.55	5.65	5.02
2008	20.44	5.54	5.96	6.11	4.68
2009	18.71	7.83	15	7.31	7.13
2010	27.13	5.93	7.8	5.39	4.47
2011	24.02	8.94	4.58	7.8	7.71
2012	19.57	5.59	3.23	4.87	7.45
2013	19.81	6.22	6.64	4.79	10.98
2014	16.61	3.92	6.91	8.63	6.25
2015	112.2	12.8	15.5	16	7.71

4.2 Materials used

- To estimate (design flood estimation) flood frequency analysis Gumble's and Log pearson type –III distributions methods are used..
- Filling rainfall missing data by Arithmetic and simple mean methods has been used.
- Double mass curve is used to check the consistency of the rainfall records.
- The homogeneity test for recording rain gauge stations.

4.3 Homogenity test of Recording Stations

The homogeneity of the selected gauging stations of daily rainfall records will be analyzed by non-dimensional equation:

$P_x = \frac{\bar{P}_i}{\bar{P}} X$

Where:

P_x Non dimensional Value of Precipitation for the month i
$\bar{P_i}$ Over years averaged monthly precipitation for the station i
$\bar{P}$ The over years average yearly precipitation of the station

The figure 3 shows below indicates the homogeneity of the data collected from different gauging station (such as; Dilla, Yirgachefe, Fsihagenet and Yabello).

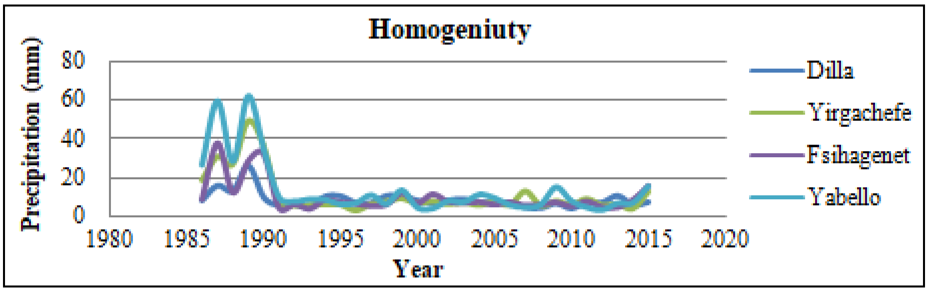

Figure 3: Homogeneity test for areal rainfall stations.

4.4 Major land use coverage of Gelana water shed

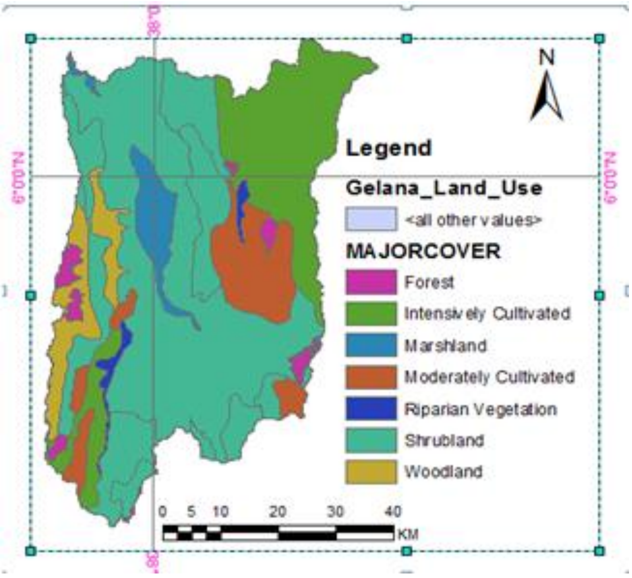

Figure 4: Major land use coverage of Gelana water shed

4.5 Gumble's Method

$$q = 1 - P \text{ ....(1)}$$

$$T = \frac{1}{p} = \frac{1}{1-q} \text{ ....(2)}$$

Gumbel makes use of a reduced varitae Y as a function of q, According to his theory of extreme value distribution events, the probability of occurring an event is equal to or larger than a value x_0 is

$$P(X \geq x_0) = 1 - e^{-e^{y}} \text{ .... (3)}$$

In which y is a non dimensional variable given by

$$y = \alpha(X - a) \text{ ------------------------------ (4)}$$

$$a = \bar{x} - 0.45005\sigma_x \text{ ....(5)}$$

$$\alpha = \frac{1.2825}{\sigma x} \text{ .... (6)}$$

$$\text{Thus } y = \frac{1.2825(x - \bar{X})}{\sigma x} + 0.57 \text{ .... (7)}$$

The original Gumble equation can be transposed as follows

$$y = -\ln(-\ln(q)) = -\ln(-\ln(1-p)) \text{ ....(8)}$$

$$y_T = -[\ln(\ln(\frac{T}{T-1}))] \text{ ....(9)}$$

4.6 Log-person type III distribution.

If X is the variate of random hydrologic series, then the series of Z variates where

$$Z = \log X \text{ --(11)}$$

Are first ordinate. For this Z series, for any recurence interval,T

$$Z_T = Z + K_Z \sigma_Z \text{ ....(12)}$$

Where K_Z = a frequency factor which is a function of recurence interval T and the the coeficient of skew C_S

σ_Z = standard deviation of the Z variate sample

$$= \sqrt{\left(\frac{\sum(Z - \bar{Z})^2}{N-1}\right)} \text{ ....(13)}$$

C_S = coeficient of skew of variate Z

$$= \frac{\sum(Z - \bar{Z})^3}{(N-1)(N-2)(\sigma Z)^3} \text{ ....(14)}$$

$\bar{Z}$ = mean of Z values

N = sample sie = number of years of record

The variations of $K_Z = f(C_S, T)$ taken from Log-pearson type III distribution Table.

$$X_T = \text{antilog}(Z_T) \text{ ....(15)}$$

5. Result and Discussion

5.1 Return period

Findings of Gumbel's Method and Log- Pearson Type III Method are compared as piloted in the table 6 below. While comparing computed values with observed values was carried out to find the best fit method, Log- Pearson Type III Method was found to be the best fit for Gelana River. The table below shows the recurrence interval of flood occurrence in the Gelana catchment.

Table 2: Return period

Return Period (Year)	Maximum flood (M^3/S)	
	Log-Pearson Type III Method	Gumble's method
2	23.7	28.0
10	52.3	69.0
25	82.0	89.6
50	114.7	104.9
100	160.2	120.1

5.2 Calibration and validation

The figures showed that the values of the scattered plot of the measured and simulated daily flows data for the calibrated and validated periods. There is a correlation between the two datasets or both measured and simulated flows. Between the measured and simulated average daily flow with coefficient of determination (R^2) value of calibration and validation 0.864 and 0.982 respectively.

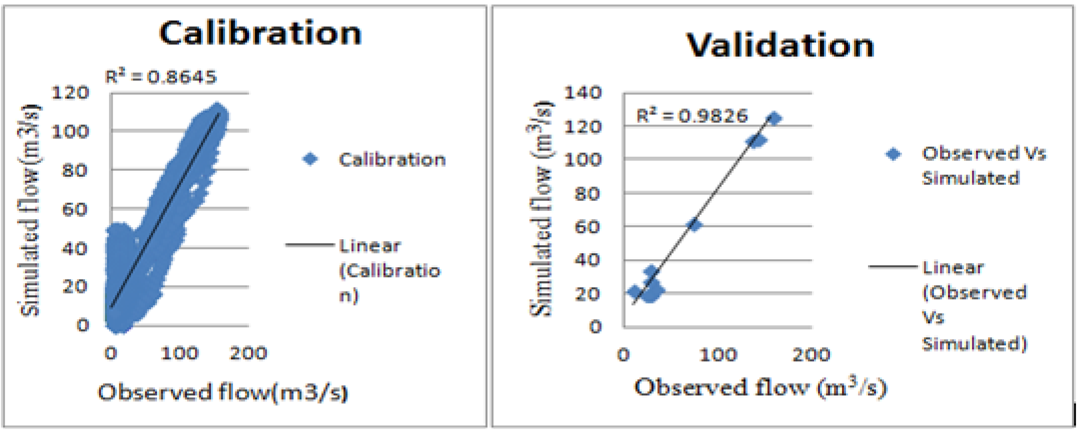

Figure 4: Scatter plots of the calibration and validation periods show the correlation of observed and simulated flow

The figure shows the calibration of observed and simulated flow. At the year 1987,1988,1989,1990 and 1993 the observed flow was higher than the simulated flow. For the years 1991, 1992, 1991, 1992, 2003 and 2005 simulated flow was larger than the observed value of flow. For the years 1986, 1994, 1995, 1996, 1997, 1998, 1999, 2001, 2002 and 2004 both observed and simulated flow were fitted.

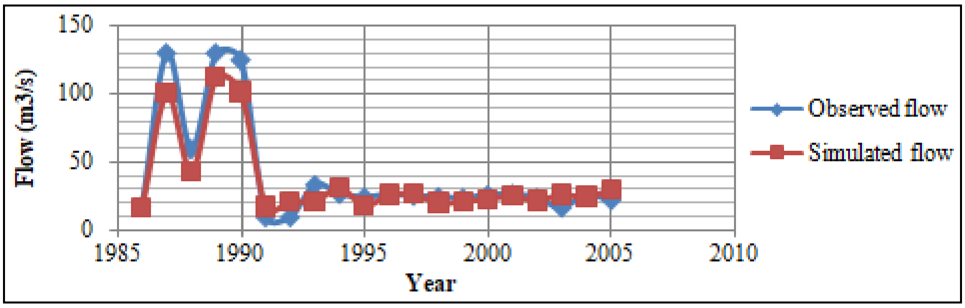

Figure 5: observed and simulated flow comparison of Calibration results at outlet

For the years, 2006, 2007, 2008, 2009, 2010 and 2012 simulated flow was lower than observed flow. For the years, 2011, 2013 and 2015 simulated flow was larger than observed flow. Based on the data collected, The reason for the flow is maximum at 2006, 2008 and 2009 is that the precipitation was maximum on the years and the flow was minimum from 2010 – 2015 because the precipitation was minimum.

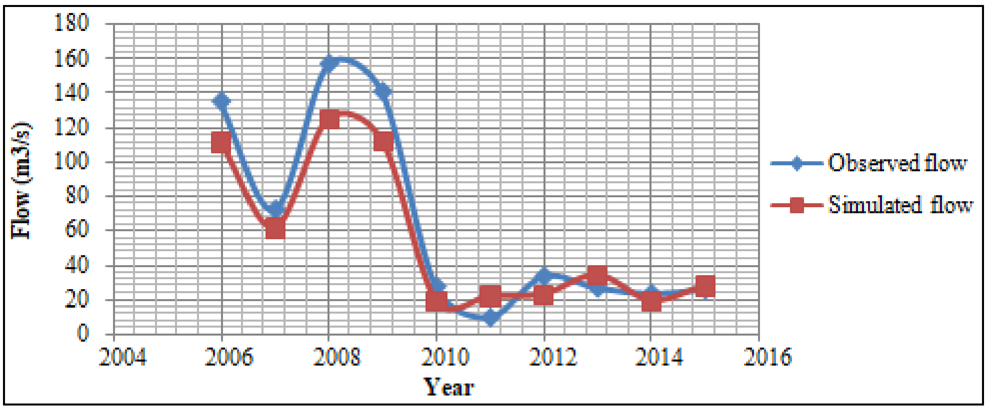

Figure 6: Observed and simulated flow comparison of validation results at outlet

6. Conclusion

Performance of the model for the calibration was found Nash-Sutcliffe coefficient value of 0.793 and R^2 value of 0.824 and for validation of the watershed were found to be reasonably very good with Nash-Sutcliffe coefficient value of 0.851 and R^2 value of 0.982. As the model run result, the model performance assessment indicates that there is a good correlation and agreement between the observed and simulated flows.

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