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Development of Rainfall Intensity Duration Frequency (IDF) Curves for Hydraulic Design Aspect

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Abstract

Rainfall is one of the major parts that constitute the hydrological cycle, when the rain falls on a built-up area, the water flowing over that area is known as storm water. The storm is characterized mainly by: Intensity, Duration and Frequency. Due to production of greenhouse gases, hydrologic cycle is changing day by day which is causing variations in terms of intensity, duration and frequency of rainfall events. By pinpointing the potential effects of climate change and adapting to them, is the one way to reduce regions susceptibility. Since rainfall characteristics are often used for planning and design of various water resources project, reviewing and bring up-to-date rainfall characteristics which is Intensity–Duration–Frequency (IDF) curves for future climate situations is important. The main objective of this study is to establish the empirical equations of rainfall intensity which can be used in the Upper Nyabarongo catchment (NNYU) for hydraulic structures design. It was found that intensity of rainfalls decreases with increase in rainfall duration. Further, a rainfall of any given duration will have a larger intensity if its return period is large. In other words, for a rainfall for a given duration, rainfalls of higher intensity in that duration are infrequent than rainfalls of smaller intensity.

Keywords: Climatic Changes; Rainfall; Intensity -Duration -Frequency Curves; Gumbel's Extreme Value Distribution

Introduction

The hydrological change is the challenge that the engineers meet in the hydraulic structures design. This is the case in Rwandan country. There is high amount of rainfall currently and these increases have a considerable impact on the hydraulic design. For instance, road drainage design was not based on maximum probable flood strategy nor taking high return period. The issue that was identified is that high capacity of runoff overtopped the banks of the channels. Other consequences being more soil erosion caused by one rainstorm of high intensity than by several storms of low intensity. Rainfall intensity (i) is an expression of the rate of rainfall (the most units used are millimeters per hour (mm/hr.)) [1]. In order to plot the amount of water falling within a given period of time, The Intensity - Duration-Frequency (IDF) are used [2-4]. Rwanda is a country located in the tropical region of the planet. Engineers predicted that it is difficult to construct the IDF curves for precipitation in the above climatic region due to the lack of long –term extreme precipitation data. Careful arrangement is adopted making a combination of limited high frequency information on rain fall peak values with long-term daily information of rainfall. Even tough, it is the case rainfall parameters including its intensity should be determined. And remember that due to climate change, precipitation increased at an alarming rate, and that sudden increase is the primary cause of floods. Flood is one of the most disasters that affect public health and economy worldwide. For the case of Rwanda, because of its geographical features (relief) and climatic profile, it is one of the sub-Saharan countries susceptible to disasters more frequently localized floods [5]. Rwanda is facing the problem of landslides, floods due to rainfall extremes. For such an issue, so many lives of vulnerable citizens were lost, destruction of public & private property, erosion and other kinds of environmental degradation had been prevalent. The major problem was how the rainfall had been managed; because it's conversion into high discharging runoffs had provoked hydrological problems to deal with [5]. To handle these problems in Rwanda by establishing intensity, duration and frequency curves and their respective empirical equations in order to deal with rainfall changes for different return periods (years). These curves can also be used to determine when an area will be flooded and when a certain rainfall rate or a specific volume of flow will be occurred again in the future. Engineers must be able to quantify rainfall in order to design the proper structures with the collection, conveyance, and storage of excess rainfall. The hydrological aspects of Rwanda, a country of thousand hills is very interesting, therefore the study of the Intensity -duration-frequency –curves will enable to design hydraulic structures for long period of time especially for a study area of upper Nyabarongo catchment. The information is required for water resources projects, sewer systems design, or water quality management projects in large urban areas such as Kigali [6]. Quantification of rainfall is generally done using intensity-duration-frequency (IDF) Curves [7]. This project will be involved in the development of intensity-duration and frequency curves in order to solve problems related to hydraulic design.

Materials and Methods

To achieve the objectives of this research by determining the intensity-duration-frequency curves for Rwanda in the upper Nyabarongo Catchment in order to generate empirical equations of rainfall intensity within the study area. Different materials and methods were used.

Intensity Duration Frequency curves

The rainfall intensity-duration-frequency relationship is one of the most widely used methods in urban drainage design and flood plain management. The establishment of such relationships goes back to as early as 1928 [8]. After Meyer had developed a few, Sherman [9] derived applicable general intensity duration formula to other localities, and Bernard [10] made available for localities within the limits of the study, rainfall intensity formulas for frequencies of 5, 10, 15, 25, 50 and 100 year, applicable to rainfall duration of 120 to 6000 min. In 1935 David Yarn ell made the first intensity –frequency maps for United State. The most known and valuable contribution to the rainfall frequency analysis occurred in TP-40(Technical Paper 40) a work of Hershfield [11]. He developed, for the entire USA, Depth-Duration-Frequency curves of precipitation of durations of 30 to 24 hours return periods of 2 to 100 years. Various works has been published to update and increase the usefulness and precision by Frederick [12]. The IDF curves as a tool of precipitation frequency estimation is much used in USA either for hydrologic purposes or engineering design. The technique is also widely used in Canada and other parts of the world where enough data of rainfall can be found, at least for30 years. In Africa, Oyebande Lekan [13] established IDF curves for Nigeria; precipitation frequency values for Kinshasa-Yangambi have been produced by Demaree GR [14]. In February 1981, the same values were published by "Service meteorology" for the cities of Kigali, Butare and Kamembe. This analysis concerned precipitations of duration of 15 min to 90 min and return period of 0.5 to 10 years. It is the only known the work done on the precipitation frequency analysis in Rwanda.

Definition of IDF curves

When in the system of coordinates, ordinates are rainfall intensities in mm/hr. and abscissas are duration in min, the parallel curves obtained for different return periods are called Intensity-Duration-Frequency curves. Veneziano [15] suggested a more scientific definition of IDF curves, as follow. Let $I(d)$ be the average of rainfall intensity in a generic interval of duration d, $I_{max}(d)$ be the annual maximum of $I(d)$, and $i_{max}(d, T)$ be the value exceeded by $I_{max}(d)$ on average every T year. The IDF curves are plots of i_{max} against d for different values of T. A curve with a return period of 1 year will show the worst storm that will on average occur every year, a curve with a return period of 10 years is the worst storm that can be expected in every 10 years, and so on. The principal characteristics of an actual or design storm are its volume, duration, and the frequency of occurrence of storms with the same volume and duration.

Study Area Description (The Upper Nyabarong Catchment)

The upper Nyabarongo catchment is a part of Nile basin and runs from south to north in the western part of Rwanda.The catchment is known as the water tower of Rwanda and boosts a significant number of tributaries,of which the most important are (from south to north) the Mwogo river (81.1 km), Rukarara River (47.4 km, springing from the Rubyiro and Nyarubugoyi Rivers), Mbirurume River (51.6 km), Mashiga River (12.2Km), Kiryango River (10.4 km), Munzanga River (24.4 km), Miguramo River (15.0 km) and Satinsyi River(59.7 Km). The surface area of the catchment is entirely contained within Rwanda is 3,347.57 Km^2. Although located at the eastern edge of the catchment, the town of Muhanga could be identified as the center point for the catchment management, with Gikongoro as the site for the Mwogo subcatchment and Kilinda For the Mbirurume River.

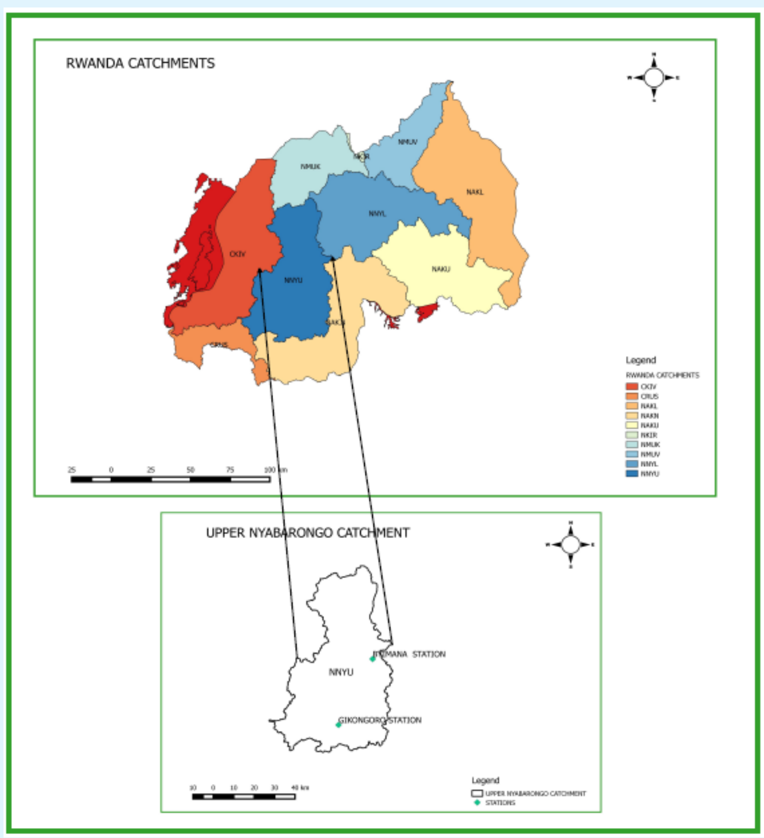

Figure 1: Upper Nyabarongo Catchment map.

The upper Nyabarongo catchment has no dependency on any upstream catchments, Hence Waterflow and quality are defined within the catchment itself. The outflow of the catchment is at the confluence of the

Mukungwa and Upper Nyabarongo Rivers where the Nyabarongo turns and takes a south easterly direction [16]. Upper Nyabarongo catchment has code of NNYU and it cover these districts: (Karongi, Ngororero, Rutsiro, Muhanga, Huye, Nyamagabe, Nyanza, Nyaruguru, Ruhango); its surface area is 3 348 Km², Average rain fall which is equal 1365 mm, its sub-catchmdents are: NNYU-1Mbirurume, NNYU-2 Mwogo, NNYU-3 Remainder; its Approx.Base flow (m^3/s) equal to 34.2 and Approx Peak Flow(m^3/s) are 207. The catchment is characterized by soil erosion from poor agricultural practices, illegal mining activities and deforestation, causing heavy siltation in Nyabarongo river and tributaries [17]. The major economic activities in Upper Nyabarongo are agriculture and livestock, hydropower, trade and mining (especially in the districts of Muhanga, Ngororero, Rutsiro, Ruhango, Nyamagabe, Huye and Nyanza) and small agro-industries.The catchment is also home to a number of coffee washing stations and tea factories.

Collection of Data

The data used in this work have been provided by the METEO-RWANDA which has the responsibility of measuring, analyzing and storing meteorological data and forecasting the weather in Rwanda. The data consisted of Daily maximum series (AMS) of rainfall depth over a period of thirty years for Gikongoro meteorological station (1980-2015) and also 36 for Byimana meteorological station (1980-2016)] for several laps of time: 10min, 20min, 30min, 60min, 120min, 180min, 360min, 720min, 144min. These are the weather station, in Upper Nyabarongo catchment that has relatively never stopped activity over 30 and 25 years for Gikongoro and Byimana, so that enough data were available to make a frequency analysis of extreme rainfalls. In This catchment however the latter has never worked in 1989 and since 1994 up to 1996 for Gikongoro station and (1994-1995); (2000-2009) for Byimana station. Data of those years METEO-RWANDA has not archived them properly due to lack of personnel and the aftermath of the Genocide of 1994. But there were some Daily AMS that has been digitized for the period 1997-2015 and 2010-2016; these have been included in this work. The gaps were filled by the information recorded in t meteorological books. These books are filled by the meteorological agents at the station; they note in, a lot of information about the daily weather among them, the rain depth given by a rain gauge after each day, the start time and end time of rainfall. Within our study area there are 2 stations used; Byimana meteorological station will be used by Ngororero, Muhanga, Ruhango and Karongi districts. However, Gikongoro station will be used by Nyamagabe, Nyanza, Huye and Nyaruguru districts in the NNYU.

Method of Deriving IDF Curves

For a deep analysis on IDF curves, different methods can be used. There are three basic distinct approaches while constructing IDF curves.

A first consists of direct estimation of IDF curves from annual maximum rainfall by the use of plotting position formula for return period expressed as T below the length of available record. This approach produces non-smooth curves, but in the few cases when a long continuous record is available [18]. This is a viable alternative. More often, long records are available only for daily rainfall. Then the empirical IDF values for d=1 day may be used to calibrate the IDF curves generated by alternative procedures or to constrain the dependence of *id, T* on *T* [19]. A second approach, mostly followed in practice involves using a parametric model for *id, T* dependence on d and it is based on the typical shape of empirical IDF curves and dependence on *T* generally relies on the fact that rainfall maxima are attracted to extreme-type distributions. A wise analysis of annual extremes helps to determine the parameters of the model using various criteria. E.g. moment matching, maximum likelihood, least squares [20].

The third approach is so complicated. It consists of fitting temporal rainfall to continuous rainfall records and then use the model to generate rainfall time-series through Monte Carlo simulations; see for example [21]. It is important to note that model based IDF curves are smoother than the empirical ones and have approximate validity also beyond the range of the historical record. The shape of IDF curves should not be associated with a specific assumption but all available data should be used in case needed. This conceptually more satisfactory approach is rarely followed in practice because of complexities of formulating rainfall models, estimating their parameters, and generating Monte Carlo samples. Research on the extreme precipitation events is currently expanding and it is hoped this approach could be made easier to use [22]. Achievements carried out in the field of pluviometry modelling use several models including selective models involving isolated events [23]. In this research, have been preferred to use the second approach so as to establish IDF relationship. The reason for the choice is that this method is simple and provides reliable results. The moment matching method will be used as the better method for determining the parameter of statistic. It has been used for IDF generation by a lot of hydrological and meteorological services in World, as the Canadian weather service, NWS National Weather Service (USA), United Kingdom, Nigeria and elsewhere [24-30].

Daily Annual Maxima Series (AMS) analysis for GIKONGORO Meteorological station

All the computation in the Tables below have been done by use of Microsoft Excel program function. As from appendix 1 μN and σN are found to be equal to 0.53622 and 1.11238 respectively for N =30. In the second column of Table 1; sampled extreme rainfall depth, in mm are ordered in descendent order. In column four values are exceedance probabilities obtained with Gringorten formula. The reduced valuable u is computed using expression. In the last column of the Table 1 are given the expected values as were directed by generated by Gumbel distribution. The mean and standard deviation of the sample and the parameters of the distribution are given below:

Year	X(Observed)	rank	p	u	X(Gumb)
2003	102.6	1	0.018592	3.975639	119.9926
2005	100	2	0.051793	2.93403	101.8434
2011	92.4	3	0.084993	2.421099	92.90593
1999	83.3	4	0.118194	2.073196	86.84399
2012	80.5	5	0.151394	1.806909	82.20413
2010	75.2	6	0.184595	1.589291	78.4123
1985	74.8	7	0.217795	1.403892	75.18187
1988	73.5	8	0.250996	1.241291	72.34866
2009	73.3	9	0.284197	1.095568	69.80955
1998	72.6	10	0.317397	0.962748	67.49527
2013	62.2	11	0.350598	0.840018	65.35678
1993	61.3	12	0.383798	0.725297	63.35786
1987	58	13	0.416999	0.616991	61.4707
1991	57.9	14	0.450199	0.513831	59.67323
1986	57.8	15	0.4834	0.41478	57.94732
1981	56	16	0.5166	0.318951	56.27758
1997	54.8	17	0.549801	0.225565	54.6504
1984	52.6	18	0.583001	0.133906	53.05331
1983	51.4	19	0.616202	0.043285	51.47431
2014	51.1	20	0.649402	-0.04699	49.90126
1992	50.1	21	0.682603	-0.13767	48.32123
1990	46.9	22	0.715803	-0.22959	46.7196
2004	45.6	23	0.749004	-0.32376	45.07879
1982	44.7	24	0.782205	-0.42147	43.37632
2007	44.5	25	0.815405	-0.52449	41.58131
2015	43.8	26	0.848606	-0.63545	39.6479
2000	43.6	27	0.881806	-0.75867	37.50089
2008	39.2	28	0.915007	-0.90227	34.9988
2006	28.8	29	0.948207	-1.08536	31.80853
1980	23.4	30	0.981408	-1.38254	26.63039

Table 1: Daily AMS Analysis for Gikongoro station.
With p: Excedeence probability, u: Reduced variable, and XG: Gumbel variable.

The histograms in Figure 2 give an idea of distribution of data. It is quite obvious that the statistic might be skewed. The distribution is detailed to the right.

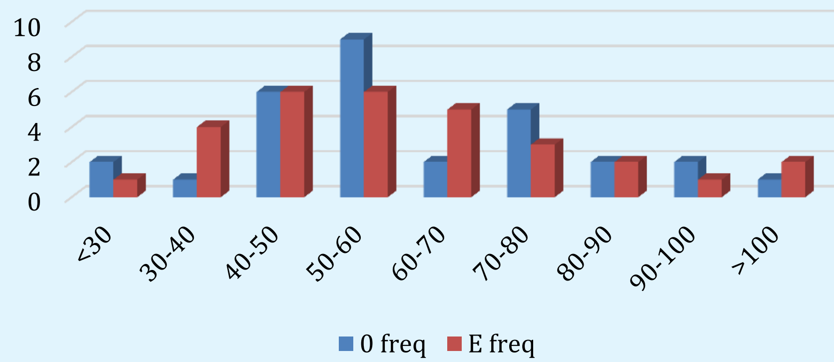

Figure 2: Distribution of Observed and Expected frequencies.
O: Observed frequency; E: Expected frequency

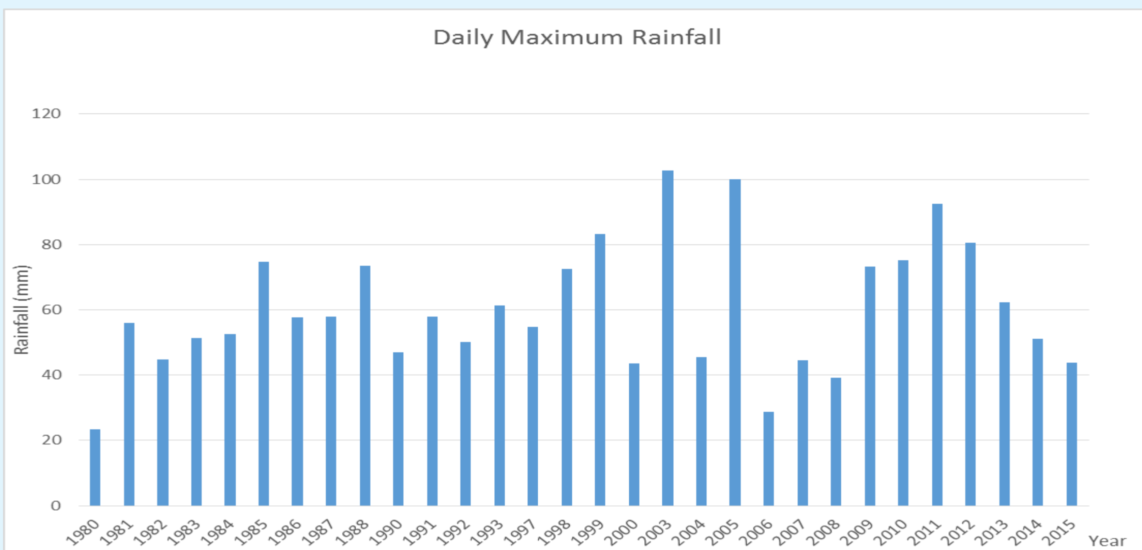

Figure 3: Annual Maximum Daily Rainfall.

NO	years	0.167hr	0.33hr	0.5hr	1hr	2hr	3hr	6hr	12hr	24hr
1	1980	4.541952	5.68664	6.52238	8.198722	10.3059	11.78138	14.80935	18.61555	23.4
2	1981	10.86963	13.60905	15.6091	19.62087	24.6637	28.19476	35.44118	44.55004	56
3	1982	8.676294	10.86294	12.4594	15.66166	19.68692	22.50546	28.28966	35.56048	44.7
4	1983	9.976767	12.49117	14.3269	18.00916	22.63775	25.87876	32.52994	40.89058	51.4
5	1984	10.20969	12.78279	14.6614	18.42961	23.16626	26.48293	33.2894	41.84522	52.6
6	1985	14.51872	18.17781	20.8493	26.20788	32.94366	37.66014	47.3393	59.50613	74.8
7	1986	11.21901	14.04649	16.1108	20.25154	25.45646	29.10102	36.58037	45.98201	57.8
8	1987	11.25783	14.09509	16.1666	20.32162	25.54455	29.20171	36.70694	46.14112	58
9	1988	14.26639	17.86188	20.487	25.7524	32.37111	37.00562	46.51655	58.47193	73.5
10	1990	9.103315	11.39758	13.0726	16.43248	20.65585	23.61311	29.68199	37.31066	46.9
11	1991	11.23842	14.07079	16.1387	20.28658	25.5005	29.15136	36.64365	46.06156	57.9
12	1992	9.724437	12.17524	13.9646	17.55367	22.0652	25.22424	31.7072	39.85638	50.1
13	1993	11.89836	14.89705	17.0864	21.47785	26.99794	30.86319	38.79544	48.76639	61.3

14	1997	10.63671	13.31743	15.2746	19.20043	24.13519	27.59058	34.68173	43.5954	54.8
15	1998	14.0917	17.64317	20.2361	25.43706	31.97472	36.55249	45.94696	57.75595	72.6
16	1999	16.16857	20.24347	23.2186	29.18605	36.68725	41.9397	52.71876	66.26819	83.3
17	2030	8.462783	10.59562	12.1528	15.27625	19.20245	21.95163	27.59349	34.68539	43.6
18	2003	19.91472	24.93373	28.5981	35.94824	45.18742	51.65682	64.93331	81.62204	102.6
19	2004	8.850984	11.08166	12.7103	15.977	20.0833	22.95859	28.85925	36.27646	45.6
20	2005	19.41005	24.30188	27.8734	35.03727	44.04232	50.34778	63.28783	79.55365	100
21	2006	5.590095	6.998942	8.02755	10.09073	12.68419	14.50016	18.22689	22.91145	28.8
22	2007	8.637474	10.81434	12.4037	15.59159	19.59883	22.40476	28.16308	35.40137	44.5
23	2008	7.608741	9.526337	10.9264	13.73461	17.26459	19.73633	24.80883	31.18503	39.2
24	2009	14.22757	17.81328	20.4312	25.68232	32.28302	36.90492	46.38998	58.31282	73.3
25	2010	14.59636	18.27501	20.9608	26.34803	33.11982	37.86153	47.59245	59.82434	75.2
26	2011	17.93489	22.45494	25.7551	32.37444	40.6951	46.52135	58.47795	73.50757	92.4
27	2012	15.62509	19.56301	22.4381	28.205	35.45407	40.52996	50.9467	64.04069	80.5
28	2013	12.07305	15.11577	17.3373	21.79318	27.39432	31.31632	39.36503	49.48237	62.2
29	2014	9.918537	12.41826	14.2433	17.90405	22.50563	25.72771	32.34008	40.65191	51.1
30	2015	8.501603	10.64422	12.2086	15.34633	19.29054	22.05233	27.72007	34.8445	43.8
	Mean	11.65833	14.59652	16.7417	21.04455	26.45329	30.24055	38.01278	47.78257	60.06333
	DTDEV.S	3.762131	4.710284	5.40254	6.791059	8.536452	9.758601	12.26669	15.4194	19.38239

Table 2: Shorter Duration Rainfalls Derived from Max. Daily Rainfall using IMD 1/3 rd. rule.

YEARS	%(Observed)	rank	p	to	X(Gumb)
2012	91.7	1	0.02229299	3.7922314	114148327
1983	84.7	2	0.06210191	2.7470928	97.2894704
2016	82.9	3	0.10191083	2.23039546	88.9547611
1990	79	4	Q14171975	1.87846445	83.2778542
1982	78.2	5	Q18152866	1.60786466	78.9127136
2014	76.6	6	0.22133758	1.38558391	75.3273273
1987	72.8	7	0.2611465	1.19515971	72.25 ^^5
1988	66.8	8	0.30095541	1.02710846	69.5443539
1986	68	9	0.34076433	0.87545068	67.0385019
2011	68	10	0.38057325	0.73613647	64851261
1992	65.8	11	0.42038217	0.60626093	62.7562727
2013	63.9	12	0.46019108	0.48363198	60.7781772
1993	63.1	13	0.5	0.36651292	588863
1980	61.9	14	0.53980892	0.25345653	57.0652774
2010	61.7	15	0.57961783	0.143.13808	55.2865659
1984	61.4	16	0.61942675	0.03451214	53.5335427
1998	61.2	17	0.65923567	-0.07377463	51.7867973
1985	57.4	18	0.69904459	-0.1829823	50.025197
1981	52.6	19	0.7388535	-0.29466295	48.2237056
1991	93.4	20	0.77866242	-0.41032819	46.3498746
2015	48.2	21	0.81847134	-0.53435173	44.3573488
1989	36.2	22	0.85828025	-0.66982932	42.1719953
1999	31	23	0.89808917	-0.82577814	39.65E4257
1997	28.6	24	0.93789809	-1.02203342	36.4898767
1996	24.4	25	0.97770701	-1.33591718	31.4275066

Table 3: Daily AMS analysis for BYIMANA Meteorological station.

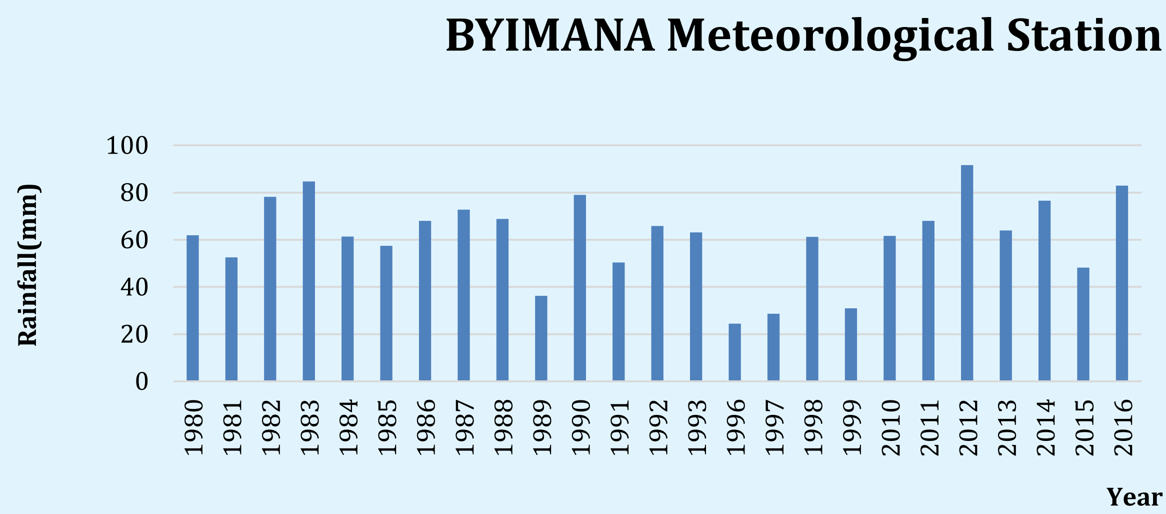

Figure 4: Annual Maximum Daily Rainfall (Byimana station).

Result and Discussion

From the raw data, the maximum rainfall (P) and the statistical variables (average and standard deviation) for each duration (10, 20, 30, 60, 120, 180, 360, 720, 1440 min) were calculated. Various duration of rainfalls like 10, 20, 30, 60, 120, 180,360, 720 and1440 min were estimated from annual maximum 24 hours rainfall data using Indian Meteorological empirical reduction formula. These estimated various duration data were used in Gumbel's Extreme Probability Method to determine rainfall (Pt) values and intensities (I_T) for two meteorological stations. Rainfall frequency (Pt) values and intensities (I_T) for different durations and return periods using Gumbel Method for Gikongoro station was computed. Similarly, for all other station, rainfall frequency (Pt) values and intensities (I_T) for different durations and return periods using Gumbel Method was computed. Both Tables 4 and 6, it was found that intensity of rainfall decreases with increase in storm duration. Further, a rainfall of any given duration will have a larger intensity if its return period is large. After finding out the rainfall (Pt) values and intensities (I_T) in Figure 5 and 6 Rainfall IDF curves are developed for two stations. Then finally for each station for each return period an equation has been developed, shown in Table 5 to table 7. It was found that the correlation coefficient for each equation is 1 which indicates a strong relationship in IDF equations.

Return period	x	y	Equations	Correlation coefficient(R)
2	309.3	0.67	$i=309.3(td)^{-0.67}$	R=1
5	402.36	0.67	$i=402.36(td)^{-0.67}$	R=1
10	464.12	0.67	$i=464.12(td)^{-0.67}$	R=1
25	542	0.67	$i=542(td)^{-0.67}$	R=1
50	599.75	0.67	$i=599.75(td)^{-0.67}$	R=1
100	675.19	0.67	$i=657.19(td)^{-0.67}$	R=1

Table 4: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Gikongoro Meteorological station.

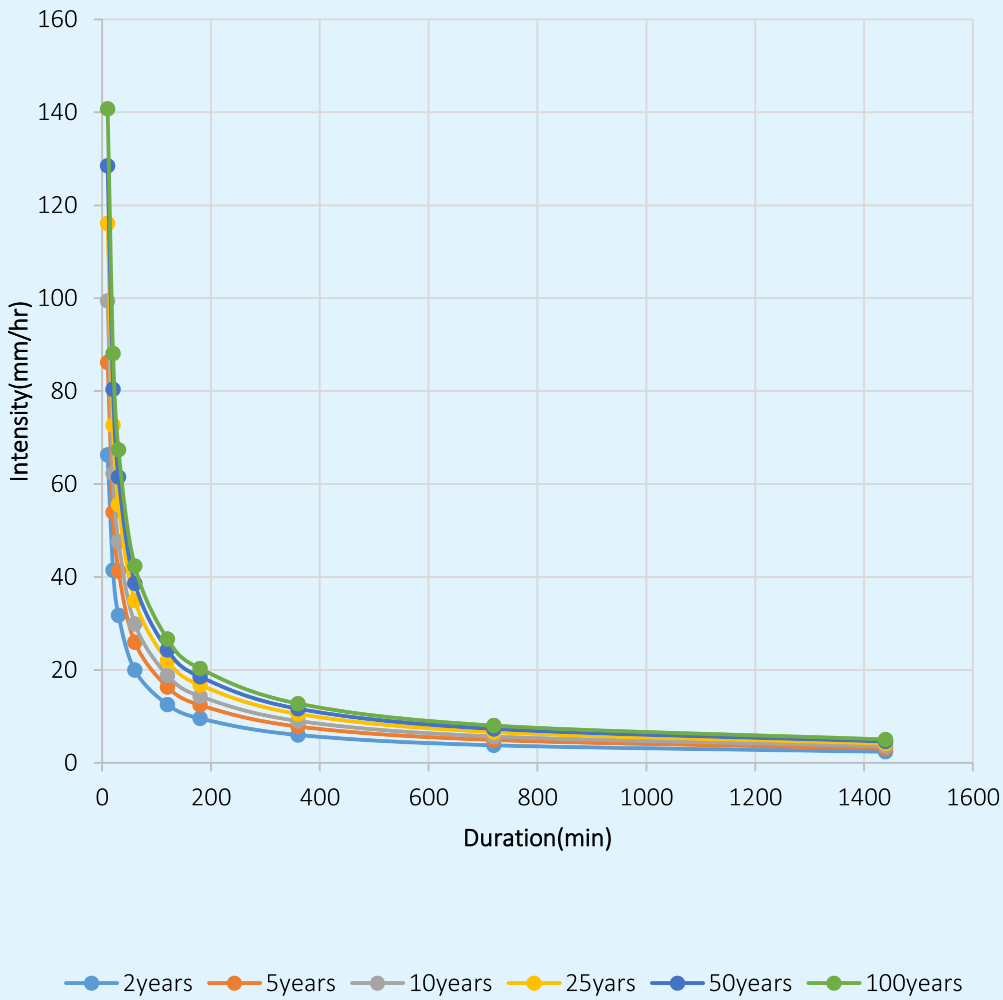

Figure 5: Rainfall IDF curve (Gikongoro station).

To estimate the maximum rainfall intensity for different duration and return periods the following empirical equation is used.

$i = x * (t_d)^{-y}$

Where,

i = rainfall intensity in mm/hr.,

t_d = rainfall duration in minutes and

x and y are the parameters to fit the IDF curve

Least Square method is used to find parameters x and y for various return periods and the results are shown in table 14 and 16.

		10min						20min						30min			
Tr (Year)	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**	**Tr (Year)**	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**	**Tr (Year)**	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**
2	11.658325	-0.164	3.762131	11.04134	66.24801	2	14.59652	-0.164	4.710284	13.82403	41.4721	2	16.74171	-0.164	5.402535	15.85569	31.71139
5	11.658325	0.719	3.762131	14.3633	86.17978	5	14.59652	0.719	4.710284	17.98321	53.94964	5	16.74171	0.719	5.402535	20.62613	41.25227
10	11.658325	1.305	3.762131	16.56791	99.40744	10	14.59652	1.305	4.710284	20.74344	62.23032	10	16.74171	1.305	5.402535	23.79202	47.58404
25	11.658325	2.044	3.762131	19.34812	116.0887	25	14.59652	2.044	4.710284	24.22434	72.67302	25	16.74171	2.044	5.402535	27.78449	55.56899
50	11.658325	2.592	3.762131	21.40977	128.4586	50	14.59652	2.592	4.710284	26.80558	80.41673	50	16.74171	2.592	5.402535	30.74508	61.49016
100	11.658325	3.137	3.762131	23.46013	140.7608	100	14.59652	3.137	4.710284	29.37268	88.11805	100	16.74171	3.137	5.402535	33.68946	67.37893
		60min						120min						180min			
Tr (Year)	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**	**Tr (Year)**	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**	**Tr (Year)**	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**
2	21.044554	-0.164	6.791059	19.93082	19.93082	2	26.45329	-0.164	8.536452	25.05331	12.52665	2	30.24055	-0.164	9.758601	28.64014	9.546714
5	21.044554	0.719	6.791059	25.92733	25.92733	5	26.45329	0.719	8.536452	32.59099	16.2955	5	30.24055	0.719	9.758601	37.25699	12419
10	21.044554	1.305	6.791059	29.90689	29.90689	10	26.45329	1.305	8.536452	37.59336	18.79665	10	30.24055	1.305	9.758601	42.97553	14.32518
25	21.044554	2.044	6.791059	34.92548	34.92548	25	26.45329	2.044	8.536452	43.90179	21.9509	25	30.24055	2.044	9.758601	50.18713	16.72904
50	21.044554	2.592	6.791059	38.64698	38.64698	50	26.45329	2.592	8.536452	48.57977	24.28989	50	30.24055	2.592	9.758601	55.53485	18.51162
100	21.044554	3.137	6.791059	42.34811	42.34811	100	26.45329	3.137	8.536452	53.23214	26.61607	100	30.24055	3.137	9.758601	60.85328	20.28443
		360min						720min						1440min			
Tr (Year)	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**	**Tr (Year)**	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**	**Tr (Year)**	**MEAN**	**K**	**S**	**PT**	**I(mm/hr)**
2	38.01278	-0.164	12.26669	36.00104	6.000174	2	47.78257	-0.164	15.4194	42.25379	3.771149	2	60.06333	-0.164	19.38239	56.88462	2.370193
5	38.01278	0.719	12.26669	46.83253	7.805422	5	47.78257	0.719	15.4194	58.86912	4.90576	5	60.06333	0.719	19.38239	73.99927	3.083303
10	38.01278	1.305	12.26669	54.02081	9.003469	10	47.78257	1.305	15.4194	67.90488	5.65874	10	60.06333	1.305	19.38239	85.35735	3.556556
25	38.01278	2.044	12.26669	63.0859	10.51432	25	47.78257	2.044	15.4194	79.29982	6.608318	25	60.06333	2.044	19.38239	99.68093	4.153372
50	38.01278	2.592	12.26669	69.80804	11.63467	50	47.78257	2.592	15.4194	87.74965	7.31247	50	60.06333	2.592	19.38239	110.3025	4.595937
100	38.01278	3.137	12.26669	76.49339	12.7489	100	47.78257	3.137	15.4194	96.15322	8.012768	100	60.06333	3.137	19.38239	120.8659	5.036078

Table 5: Computed frequency rainfall (PT) values and intensities (IT) for different durations and return periods using Gumbel for GIKONGORO Meteorological Station.

			10min						20min						30min		
Tr (Year)	**MEAN**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**	**Tr (Year)**	**MEAN(σ)**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**	**Tr (Year)**	**MEAN(σ)**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**
2	11.9449467	-0.164	3.417313	11.3845074	68.3070444	2	14.9553776	-0.164	4.27856339	14.2536932	42.7610796	2	17.1533079	-0.164	4.90736625	16.3484998	32.6969997
5	11.9449467	0.719	3.417313	14.4019948	86.4119687	5	14.9553776	0.719	4.27856339	18.0316647	54.094994	5	17.1533079	0.719	4.90736625	20.6817042	41.3634085
10	11.9449467	1.305	3.417313	16.4045402	98.4272412	10	14.9553776	1.305	4.27856339	20.5389028	61.6167084	10	17.1533079	1.305	4.90736625	23.5574209	47.1148417
25	11.9449467	2.044	3.417313	18.9299345	113.579607	25	14.9553776	2.044	4.27856339	23.7007612	71.1022835	25	17.1533079	2.044	4.90736625	27.1839645	54.3679291
50	11.9449467	2.592	3.417313	20.802622	124.815732	50	14.9553776	2.592	4.27856339	26.0454139	78.1362417	50	17.1533079	2.592	4.90736625	29.8732012	59.7464025
100	11.9449467	3.137	3.417313	22.6650576	135.990346	100	14.9553776	3.137	4.27856339	28.3772309	85.1316928	100	17.1533079	3.137	4.90736625	32.5477158	65.0954317
			60min						120min						180min		
Tr (Year)	**MEAN**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**	**Tr (Year)**	**MEAN(σ)**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**	**Tr (Year)**	**MEAN(σ)**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**
2	21.5619375	-0.164	6.16862501	20.550283	20.550283	2	27.1036438	-0.164	7.75404414	25.8319805	12.9159903	2	30.9840223	-0.164	8.86417629	29.53.2947	9084343245
5	21.5619375	0.719	6.16862501	25.9971788	25.9971788	5	27.1036438	0.719	7.75404414	32.6788015	16.3394008	5	30.9840223	0.719	8.86417629	37.357365	12.452455
10	21.5619375	1.305	6.16862501	29.6119931	29.6119931	10	27.1036438	1.305	7.75404414	37.2226714	18.6113357	10	30.9840223	1.305	8.86417629	42.5517723	14.1839214
25	21.5619375	2.044	6.16862501	34.170607	34.170607	25	27.1036438	2.044	7.75404414	42.95291	21.476455	25	30.9840223	2.044	8.86417629	49.1023986	16.3674662
50	21.5619375	2.592	6.16862501	37.5510135	37.5510135	50	27.1036438	2.592	7.75404414	47.2021262	23.6010631	50	30.9840223	2.592	8.86417629	53.9599672	17.9866557
100	21.5619375	3.137	6.16862501	40.9129141	40.912914	100	27.1036438	3.137	7.75404414	51.4280803	25.7140401	100	30.9840223	3.137	8.86417629	58.7909433	19.5969811
			360min						720min						1440min		
Tr (Year)	**MEAN**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**	**Tr (Year)**	**MEAN(σ)**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**	**Tr (Year)**	**MEAN(σ)**	**K**	**S**	**Pt(σ+K*S)**	**I(mm/hr)**
2	38.9473304	-0.164	11.1423881	37.1199787	6.18666312	2	48.9573152	-0.164	14.0061309	46.6603097	3.88835914	2	61.54	-0.164	17.6058939	58.6526334	2.44385973
5	38.9473304	0.719	11.1423881	46.9587075	7.82645125	5	48.9573152	0.719	14.0061309	59.0277233	4.91897695	5	61.54	0.719	17.6058939	74.1986377	3.0916099
10	38.9473304	1.305	11.1423881	53.4881469	8.91469115	10	48.9573152	1.305	14.0061309	67.2353161	5.60294301	10	61.54	1.305	17.6058939	84.5156915	3.52148715
25	38.9473304	2.044	11.1423881	61.7223718	10.287062	25	48.9573152	2.044	14.0061309	77.5858468	6.44568724	25	61.54	2.044	17.6058939	97.5624471	4.06360196
50	38.9473304	2.592	11.1423881	67.8284005	11.3047334	50	48.9573152	2.592	14.0061309	58.2612066	7.10510055	50	61.54	2.592	17.6058939	107.174477	4.46560321
100	38.9473304	3.137	11.1423881	73.901002	12.3168337	100	48.9573152	3.137	14.0061309	92.8945479	7.74121233	100	61.54	3.137	17.6058939	116.769689	4.86540372

Table 6: Computed frequency rainfall (PT) values and intensities (IT) for different durations and return periods using Gumbel for BYIMANA Meteorological Station.

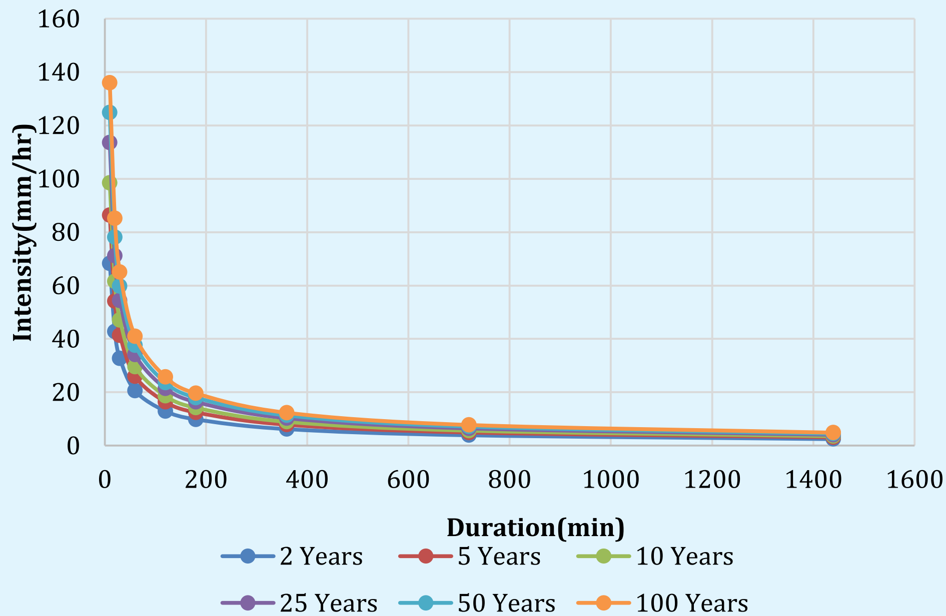

Figure 1: Rainfall IDF curve (Byimana station).

Return Period (Years)	X	Y	Equation ($i=X^*(td)^{-y}$)	Correlation coefficient
2	318.91	-0.67	$i=318.91(td)^{-0.67}$	R=1
5	447.79	-0.686	$i=403.44(td)^{-0.67}$	R=1
10	459.54	-0.67	$i=459.54(td)^{-0.67}$	R=1
25	530.28	-0.67	$i=530.28(td)^{-0.67}$	R=1
50	582.74	-0.67	$i=582.74(td)^{-0.67}$	R=1
100	634.92	-0.67	$i=634.92(td)^{-0.67}$	R=1

Table 7: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for BYIMANA Meteorological station.

Conclusion and Recommendations

This research presents some insight into the way in which the rainfall is estimated in Upper Nyabarongo catchment. The results obtained showed a good match between the rainfall intensity computed by the method used and the values estimated by the calibrated formula with a correlation coefficient of greater than 0.98. This indicated the goodness of fit of the formula to estimate IDF curves in the region of interest for durations varying from 10 to 1440 min and return periods from 2 to 100 years. They will be used in design of safe and economical drainage facilities and operation or maintenance of municipal water management infrastructures such as culverts, drain, sewers, conveyance systems, bridges, roads, etc.... for Upper Nyabarongo catchment and its environs. Further researches should be conducted all around the country (in the remaining catchments) because this research emphasized on the single central catchment only, this will lead to the generation of empirical equations of rainfall intensity which will be used in the hydraulic design of the conveyance structures in Rwanda [31-37].

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