Statistical Analysis of Rainfall Data: A Case Study of Georgetown, Guyana

Shanomae Oneka Eastman [1], Basheer Khan [2]

[1] Department of Civil Engineering, [2] Department of Mechanical Engineering,
[1, 2] Faculty of Engineering and Technology, University of Guyana
Guyana

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Abstract
Rainfall is a key component for designing of many engineering projects, including canals, bridges, culverts, and road drainage systems. This research will provide useful information to water resource planners, farmers, and urban engineers for analysis of water availability and for building appropriate engineering structures. In order to calculate the appropriate input value for the design and analysis of engineering structures as well as for crop planning, a thorough statistical study is required. The Botanical Gardens rain-gauge station in Georgetown was selected for analysis as Georgetown experiences frequent floods. The mean, standard deviation and coefficient of variation, skewness and kurtosis of monthly and annual rainfall for a 30 year period were analyzed. According to the computed data, the rainfall pattern is unpredictable, as demonstrated by the coefficient of variation. The variability in rainfall for May, June and July are (38%, 35% and 37%) respectively are much lower than the other months. An analysis of the average monthly rainfall data shows a bi-modal yearly rainfall pattern. Various plotting position formulae and probability distribution functions were used to analyze the return period of the yearly rainfall. It was determined that the Chegodayev technique provides the best fit distribution for yearly rainfall data using the plotting position method, whilst the Gumbel's Extreme Distribution yields the highest value for rainfall for various return periods using the probabilistic methods. Chegodayev technique also provides the best fit annual one day maximum rainfall for the plotting position methods The Chegodayev technique projects that rainfall for 5, 10, 50, 100 and 150 year return period are 2668.31 mm, 3024.23 mm, 3850.65 mm 4206.56 mm and 4414.76 mm whilst Gumbel's Extreme Distribution projects rainfall of 2761.54 mm, 3090.30 mm, 3813.85 mm, 4119.73 mm and 4298.10 mm respectively for the same periods. It should be noted that the result from the plotting position formulae are usually good for small extrapolations as errors increases with the amount of extrapolations.

Keywords: Statistical Analysis, Descriptive Analysis, Return Period, Rainfall Data, Guyana

1. Introduction
Rainfall on Guyana's coast is caused by mesoscale synoptic systems that occur all year, as well as large-scale systems related to the seasonal passage of the Inter Tropical Convergence Zone (ITCZ) (Shaw,

1987). According to Quantick (2008), the ITCZ, also known as the Equatorial Trough, is a zone of separation between air masses brought by trade winds from regions on either side of the Equator. It is located inside the tropics. Although this zone is referred to as a source region, the ITCZ's north-south migration and the boundaries of the permanent high-pressure belts limit the surface excursion of air originating in this zone. Holton et al. (1971) as cited in Shaw (1987) noted that moisture is provided by the moist, converging low-level airflows inside this zone, where precipitation surpasses evaporation by a factor of two or more.

This geographical variance in climate is caused by various factors, including differences in height, terrain, closeness to water bodies, notably the Atlantic Ocean, and other local characteristics such as soil type and the amount and type of vegetation cover (Ramraj, 1996). In this context, Persaud (1977) as cited in Ramraj (1996), noted that when the Koeppen climatic classification (based on annual and monthly means of temperature) is used, Guyana's climate may be broadly separated into two regions: (a) tropical wet climate and (b) tropical savannah. When Thornthwaite's classification system is applied, the country's climate is separated into three climate regions: (a) wet tropical, (b) humid tropical, and (c) humid tropical savannah.

The analysis of Guyana’s coastal rainfall is extremely important because it is low lying and extremely susceptible to Atlantic Ocean floodwaters as well as floodwaters brought on by significant precipitation (Shaw, 1987). He noted that the coastal plain rises just 10 cm/km throughout its entire length, beginning at the low water mark on the coast to around 18 km inland. With an average height of less than 2 m above sea level, this area has a flat terrain. According to Ramraj (1996), the coastal plain has a width of 10 miles (16 km) in the north and grows equally wider in the south and east. It finally reaches a width of 40 miles (64 km) at the Corentyne River, which forms the border with Suriname. Shaw (1987) noted that field crops like rice and sugar, are widely grown throughout the coastal plain, and are most suited for its production.

Rain-fed agriculture is the foundation of Guyana's national economy and food security, hence the influence of rainfall variability is quite significant. Shaw (1987) mentioned that rainfall on Guyana’s coast varies greatly spatially and temporally and the unpredictability has frequently harmed agricultural production. Furthermore, moisture availability, like other parts of the Tropics, has a primary climatic influence on agricultural growth in Guyana. The two main rainfall seasons beginning dates can vary, and dry spells alternating with periods of abundant rainfall cause problems for farmers. Due to yearly variations in the timing of the commencement of the rainy season, adequate rainfall does not always coincide with crop growth phases. Most of the coastal plain, which includes roughly 90% of the areas now under cultivation lacks appropriate artificial irrigation as a result, crop production is entirely rain-fed. He further noted that the moisture range during which field preparation commences, as well as when planting and harvesting may occur, is determined by the rainfall distribution. The rainfall regime also limits the introduction of hybrid plant kinds that require a continual supply of moisture, as well as novel agricultural practices.

Arvind et al. (2017) noted that crop yield, notably in rain-fed locations, is dependent on rainfall patterns, making it critical to forecast the probability of occurrence of rainfall utilizing historical records of hydrological data. Probability distribution aids in relating the severity of extreme events such as severe storms, floods and droughts to the number of occurrences so that their likelihood of occurrence with time may be easily predicted. The examination of rainfall data for probability and frequency allows us to predict rainfall at various chances. Rainfall with a likelihood of 80% may be regarded certain rainfall, while a probability of 50% can be considered the upper limit for accepting any risk (Gupta et al., 1975 as cited in Bhakar, 2008). Rain prediction and crop planning done analytically could be an important instrument in farmers' hands for greater economic returns (Bhakar, 2008). The hydrological data is evaluated to fit the distribution, and data variability is analyzed using statistical parameters.

This study's main goal is to conduct an analysis of rainfall for the Botanical Gardens using statistical techniques. In this study, 30 years (1989-2018) rainfall are used since they offer a constant time frame for analysis. Based on the observed data, findings from the analysis will provide extensive information on the estimated maximum rainfall to be predicted for the various return times. This analysis will be extremely important for irrigation engineers and water planners for selecting the best crops to produce in the area, designing irrigation schemes, building rainwater harvesting structures, and designing water infrastructures. For example, Juan-García (2017) mentioned that waste-water infrastructure planning must now consider extremes climate change, which affect discharge to treatment and receiving streams. Previously, Shaw (1987) studied daily rainfall data for the years 1947-1977 from a selected sample of stations to determine the beginning dates of effective and persistent rainfall within the two major rainy seasons. Ramraj (1996) studied rainfall distribution along Guyana’s coast for the period 1901-1980. He discovered that rainfall was higher from 1941 to 1980 than in the previous 40 years, and that there was inter-annual and inter-decadal fluctuation over the research period.

2. Study Area

Rainfall gathered from the Botanical Gardens was used in this study. The Botanical Gardens is located in latitude 6° 48' 0" and longitude 58° 8' 0" and is found in Guyana's capital, Georgetown. Figure 1 depicts a map of the research area. Georgetown is found on and around a drainage system that was initially utilized for the drainage of sugar cane farms. Georgetown's northern and western boundaries are the Atlantic Ocean and the Demarara River. According to Icaros Geosystems B.V. (2010) as cited in Delft University of Technology (2016), one of Georgetown's distinguishing features is that its elevation is lower than the mean sea level.

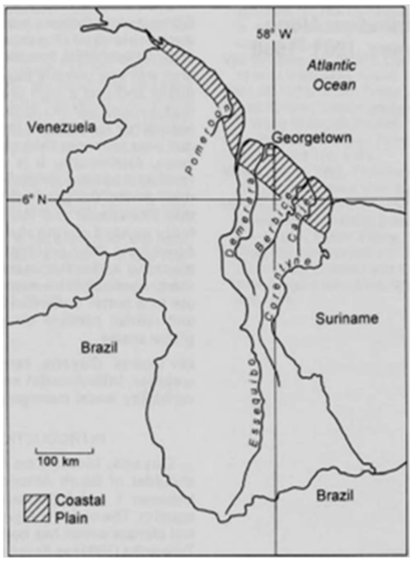

Figure 1: Coastal Plain of Guyana and Location of Climatic Stations
Source: Ramraj, 1996

3. Method

Daily, monthly and annual precipitation data of 30 years (1989-2018), were collected from the Hydrometeorological Office, Ministry of Agriculture for the rain gauge station located in the Botanical Gardens, Georgetown. The long-term variability and trend of the area's rainfall pattern were evaluated using statistical techniques such as mean, standard deviation, skewness, kurtosis, and coefficient of variation on these data. The return period of yearly rainfall was also evaluated using plotting position formulas such as Califonia, Hazen, Weibull, Chegodayev, Blom and Gringorten. Because many events in hydrology are seen as part of a continuous processes, continuous distributions such as normal, lognormal, Gumbel, Pearson type III, and log Pearson type III may be applied to the measured hydrologic variable (Manikandan, et al. 2011). The latter three types were used for the determination of extreme values in this study. Frequency or probability distribution aids in connecting the size of extreme events, such as floods, droughts, and severe storms, with their frequency of recurrence so that their likelihood of occurring over time may be anticipated (Arvind et al. 2017). It is commonly recommended that a return period of 2 to 100 years be used for soil and water conservation measures, dam building, irrigation and drainage works (Mistr & Suryanarayana, 2019), therefore estimated rainfall is calculated for 2, 5, 10, 25, 50, and 100 years.

Plotting Position Methods

Table 1 shows the plotting position methods used in this research. These are the most commonly used empirical equations for determining P, according to Subramanya (2013). The results from these methods are usually good for small extrapolations as errors increases with the amount of extrapolations.

Table 1: Plotting Position Methods

Plotting Position Method	Equation for P
California	$\frac{m}{N}$
Weibull	$\frac{m}{(N+1)}$
Hazen	$\frac{(m-0.5)}{(N)}$
Chegodayev	$\frac{m-0.3}{(N+0.4)}$
Blom	$\frac{m-3/8}{(N+1/4)}$
Gringorten	$\frac{m-0.44}{(N+0.12)}$

Where, m is rank of the data, and N = number of the sample (no. of years).

To determine the return period, the rainfall data were ranked in descending order and several plotting positions and probabilistic methods were used. The rainfall-return period equation acquired from the graphs for the different plotting position methods were used to determine the rainfall magnitudes for various return periods

Probabilistic Methods (Source: Subramanya, 2013)

The most commonly used frequency distribution functions are the Gumbel's extreme value distribution and Log-Pearson Type-III Distribution. They are most widely used in hydrological and meteorological analyses for extreme values. The steps followed for the different methods are:

Gumbel's Method

- Calculation of the mean ($\bar{x}$) and standard deviation (σ_{n-1}).
- Determination of the reduced mean y_n and reduced standard deviation S_n appropriate to the given sample size N, using the relevant table.
- Calculation of the reduced variation $Y_T = -[\ln . \ln \frac{T}{T-1}]$ for the various return periods (T).
- Determination of the frequency factors $K = \frac{Y_T - Y_N}{S_N}$.
- Determination of the required rainfall $x_T = \bar{x} + K\sigma_{n-1}$ for different return periods.

Log-Pearson Type-III Distribution

- Calculation of the variate z = log *x*, $mean(\bar{Z})$, standard deviation of the variate sample $\sigma_z = \sqrt{\sum (z-\bar{z})^2 / N-1}$, and coefficient of skew $C_S = \frac{N\sum (z-\bar{z})^3}{(N-1)(N-2)(\sigma_z)^3}$.
- Determination of the frequency factors (K_z) from the relevant table and for the required recurrence (T).
- Calculation of the value $Z_T = \bar{Z} + K\sigma_z$. The antilog of Z_T is the required rainfall X_T.

Log-Normal Distribution

The log-normal distribution is a specific case of the log-Pearson type III distribution when $C_S = 0$. According to Subramanya (2013), these are used for accurate work.

4. Data Analysis

Yearly Rainfall Analysis

The Botanical Gardens rainfall distribution has been analyzed for 30 years (1989–2018). The annual rainfall and average are depicted in Figure 2. The greatest rainfall (3536 mm) occurred in 2008, followed by 3,315.50 mm occurring in 2005. The minimum rainfall (1,592.20 mm) occurred in 2001, and the second-lowest year (1,696.50 mm) occurred in 1995. It is shown that the average annual rainfall for the 30 year period is 2339.3 mm. It should be mentioned that Guyana experienced devastating floods in 2005 as a result of five days of continuous torrential rainfall (starting on the 14th of January) along with high tides resulting in overtopping of the deteriorating water conservancy. Consecutive rainfall of magnitudes 131.7 mm, 88.8 mm, 166.1 mm, 127 mm and 136 mm were reported for a five day period. At no other time in 2005 was such high magnitude of rainfall produced continually. January 2005 experienced 942.1 mm rainfall out of the 3,315.5 mm rainfall that year. For the year 2008, December received the highest rainfall of 919.6 mm out of 3536 mm, with high magnitude rainfall of 91 mm, 115.5 mm and 91.6 mm produced on the 5th, 10th and 11th. The average annual rainfall for Ramraj (1996) studies on rainfall for the period 1901-1980 was 2330 mm, slightly lower than this study.

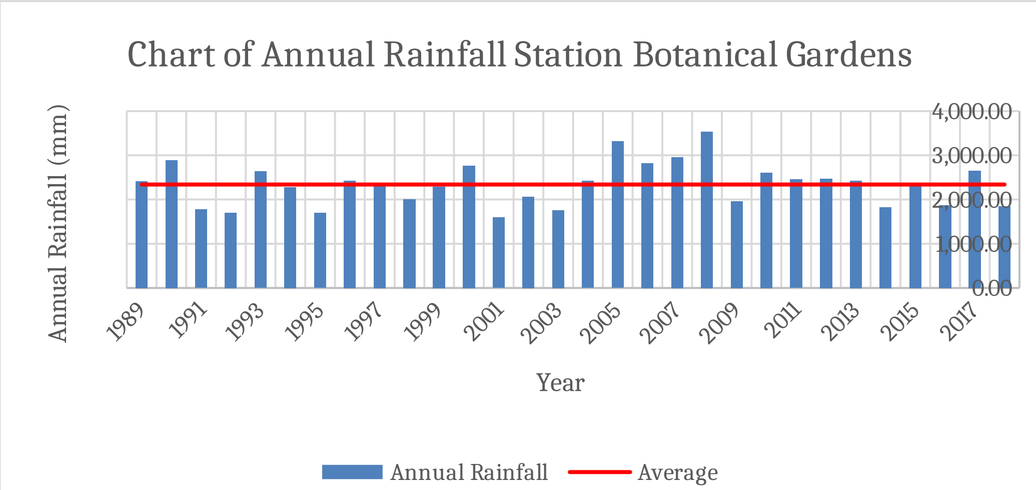

Figure 2: Annual Rainfall for the Botanical Gardens

Table 2 displays the descriptive parameters for annual rainfall from 1989-2018. The fairly high standard deviation value of 487.34 indicates that there is a significant variance in the annual rainfall values. The rainfall is erratic, as evidenced by the coefficient of variation, which measures how far data points in a data series are from the mean and is determined to be 21%. With an average value of 0.49, skewness which is a measure of asymmetry around the mean in frequency distributions indicates that the annual precipitation is asymmetric and skewed to the right of the mean. Kurtosis, a measure of how peaky or flat a frequency distribution is, has a value of -0.04, which is near to zero and suggests that it has a mesokurtic distribution.

Table 2: Descriptive Parameters for Annual Rainfall from 1989-2018

Description	Descriptive Statistics
Mean Rainfall (mm)	2339.33
Standard Deviation	487.34
Co-efficient of Variation	21%
Skewness	0.49
Kurtosis	-0.04

Plotting Position Methods

Table 3 shows the annual rainfall for different return periods for the different plotting positions. The California method yields the highest value for rainfall for various return periods, whereas the Hazen method yields the lowest value and is hence unsuitable for the analysis. Unlike other methods of distribution, the Chegodayev approach offers a maximum rainfall that is roughly 99.7% of the average maximum rainfall and offers the best fit distribution for yearly rainfall data. The Chi-square test was also used to assess the fit of these distributions. Chegodayev method provides the lowest Chi-square and was determined to be the best match for the distribution.

Table 3: Maximum Annual Rainfall (mm) - Based on Different Plotting Position Methods

Method/Return Period	5	10	50	100	150
Weibull	2705.97	3088.66	3977.23	4359.91	4583.77
Califonia	2724.07	3106.76	3995.33	4378.01	4601.87
Hazen	2638.86	2973.18	3749.45	4083.77	4279.33
Chegodayev	2668.31	3024.23	3850.65	4206.56	4414.76
Blom	2657.83	3006.13	3814.85	4163.15	4366.89
Gringorten	2648.19	2989.45	3781.85	4123.11	4322.74
Average	**2673.87**	**3031.40**	**3861.56**	**4219.09**	**4428.23**

Ponce (1989) stated that larger rainfall depths are usually linked to longer return periods. Rainfall data over a long period are required for determination of annual rainfall statistical properties. Ponce (1989) mentions that to predict rainfall depths linked to long return periods, extrapolation is necessary due to the scantiness of long rainfall records.

The rainfall for any return period can be projected, using the equation of the line, as shown in figure 4. Using Chegodayev plotting position method, the exceedance probability of the greatest rainfall of 3536 mm recurring is 2.3% and the second highest rainfall of 3,315.50 mm which resulted in the 2005 flood is 5.6%.

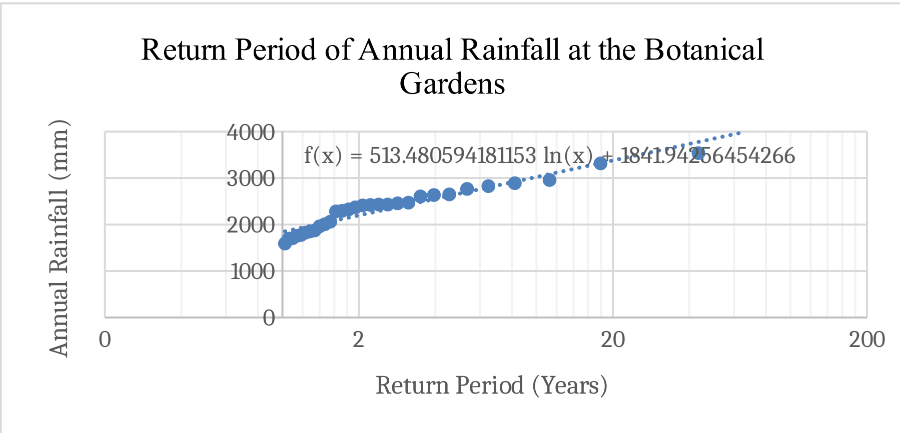

Figure 3: Return Period of Annual Rainfall at the Botanical Gardens

Probabilistic Methods

Table 4 shows the annual rainfall for different return period for the different probabilistic methods. The Gumbel's Extreme Distribution yields the highest value for rainfall for various return periods, whereas the Log normal Distribution yields the lowest value. Gumbel distribution (Extreme value type-I) provides a value that is closer to the actual value. The same approach was adapted by Arvind et al. (Jul 2017) for finding the best fit.

Table 4: Maximum Annual Rainfall (mm) - Based on Probabilistic Methods

Method/Return Period (yrs)	5	10	50	100	150
Gumbel's Extreme Distribution	2761.54	3090.30	3813.85	4119.73	4298.10
Log-Pearson Type III Distribution	2533.64	2989.88	3560.22	3738.62	3840.93
Log Normal Distribution	2530.96	2987.13	3504.25	3707.03	3804.12

Monthly Rainfall Analysis

According to Shaw (1987) the Inter Tropical Convergence Zone has a direct impact on this region between June and December, hence the yearly rainfall distribution at the coastal stations often exhibits a bi-modal pattern with substantial maxima in both months. The Inter Tropical Convergence Zone directly affects the two wet regions. He further mentioned that two rainy seasons have traditionally been distinguished: (1) a long wet season that lasts from mid-April to the middle of August, and (2) a short wet season that lasts from mid-November to the middle of February. The long dry season and short dry season are names for the interim times. However, due to the seasonal unpredictability, clear alternating wet and dry seasons are not manifested in a given year, which might cause agricultural yields to change. A plot of the mean monthly rainfall data for the period 1989–2018 is depicted in Figure 4 which shows a bi-modal yearly rainfall pattern for rainfall collected at the Botanical Gardens.

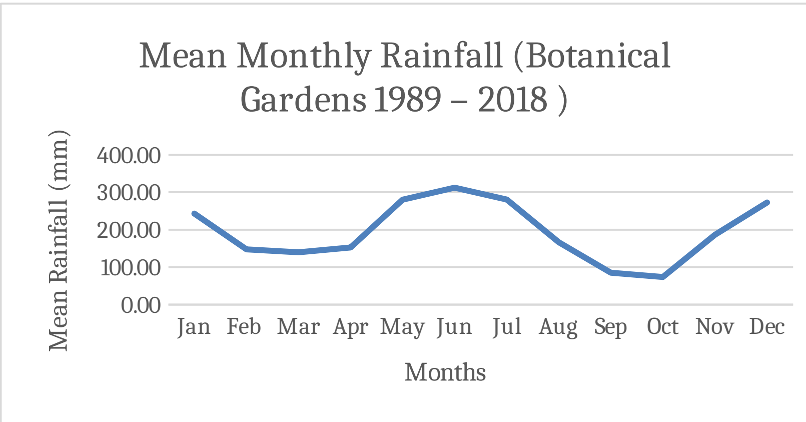

Figure 4: Mean Monthly Rainfall of the Botanical Gardens

Descriptive Parameters.

From Table 5, it is observed that higher average rainfall values are received in the months of May, June and July (280.1, 312.14 and 280.47 mm respectively) and November, December and January (243.1, 272.48 and 243.10 mm) representing the two rainy seasons. The standard deviation values are less than the corresponding mean values with the exception of March indicating the largest variation in the distribution of rainfall for that month. A high variability is noted in rainfall data for January, February and March (89%, 82% and 108%) respectively and lower variability in rainfall for May, June and July (38%, 35% and 37%) respectively.

Table 5: Descriptive Parameters for Monthly Rainfall Analysis

Months	Mean Rainfall (mm)	Standard Deviation (mm)	Co-efficient of variation	Skewness	Kurtosis	Minimum (mm)	Maximum (mm)
January	243.10	216.06	89%	2.44	8.24	20.60	1108.20
February	147.46	121.44	82%	1.25	0.98	18.20	474.70
March	139.74	151.40	108%	2.43	6.64	23.10	708.00
April	152.38	106.56	70%	0.62	-0.80	13.60	361.50
May	280.10	105.89	38%	-0.12	-0.39	58.30	477.60
June	312.14	110.07	35%	0.14	-0.82	102.80	528.80
July	280.47	102.69	37%	0.53	-0.55	108.40	510.80
August	166.25	94.40	57%	0.90	0.37	16.20	399.10
September	85.11	51.30	60%	0.47	-0.71	2.10	184.20
October	73.70	49.68	67%	1.00	0.29	11.70	194.40
November	186.39	117.20	63%	1.36	3.66	26.40	589.10
December	272.48	184.05	68%	1.74	4.20	78.30	919.00

From the above table it is clear that the data series are generally positively skewed, with the exception of May which is slightly negatively skewed. The range of kurtosis for all the data series is from -0.71 to 8.24. Negative kurtosis, which denotes flat distributions, and is seen in the months of April through July and September, whereas positive kurtosis, which denotes peaked distributions, is visible in all other months.

Annual One Day Maximum Rainfall Analysis (AODMR)

Figure 5 displays the one day maximum daily rainfall for the period 1989 to 2018. A maximum value of 210.2 mm was recorded on July 15, 2015 and a minimum value of rainfall 68 mm was recorded July 08, 2003. The average one day maximum for the period was 109.69 mm. It should be noted that Administrative Regions 3, 4 and 5 experienced severe flooding as a result of the heavy rainfall that occurred on July 15, 2015.

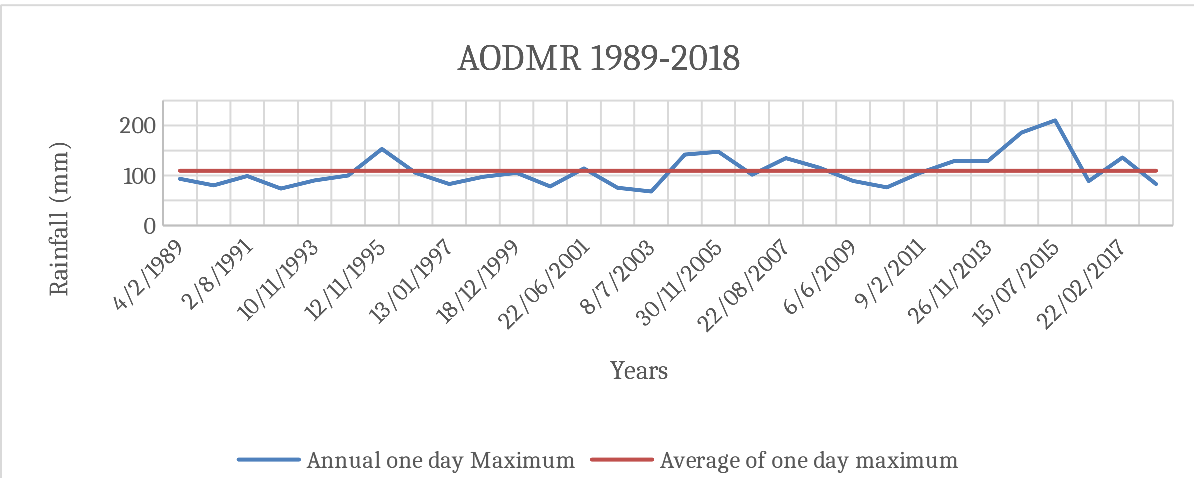

Figure 5: Annual One Day Maximum Rainfall

Values of the standard deviation, skewness and kurtosis are shown in Table 6. The coefficient of variation, which measures how far data points in a data series are from the mean and is determined to be 31%. With a skewness value of 1.3, the AODMR is asymmetric and skewed to the right of the mean. Kurtosis, with a value of -0.04, suggests that it has a mesokurtic distribution.

Table 6: Descriptive Parameters for AODMR Rainfall from 1989-2018

Description	Descriptive Statistics
Maximum Value (mm)	210.2
Minimum Value (mm)	68
Average of One Day Maximum Rainfall (mm)	109.69
Standard Deviation (mm)	33.72
Co-efficient of Variation	31%
Skewness	1.3
Kurtosis	-0.04

Probabilistic Methods

The lowest Chi-square is provided by the Chegodayev method for the AODMR, and it is the best fit.

Table 7: Maximum AODMR (mm) - Based on Plotting Position Methods

Method/Return Period	5	10	50	100	150
Weibull	135.86	163.18	226.62	253.94	269.92
Califonia	137.15	164.47	227.91	255.23	271.22
Hazen	131.29	155.41	211.42	235.54	249.65
Chegodayev	**133.30**	**158.86**	**218.19**	**243.75**	**258.70**
Blom	132.59	157.64	215.80	240.85	255.50
Gringorten	131.93	156.52	213.60	238.18	252.56
Average	**133.69**	**159.34**	**218.92**	**244.58**	**259.59**

Figure 6 graphically depicts the expected AODMR for the various probability distributions.

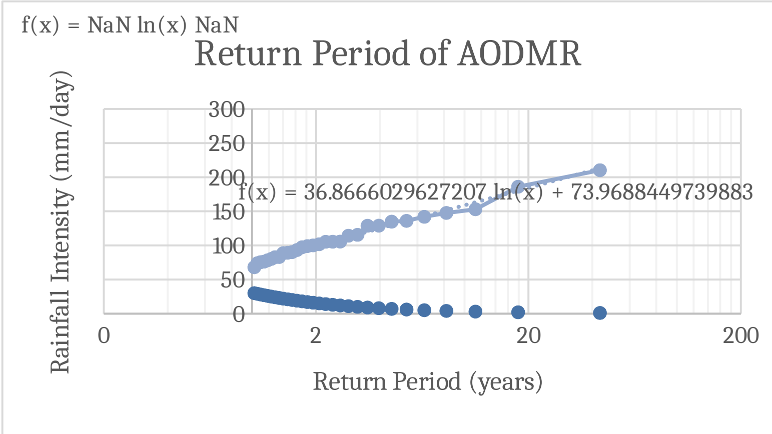

Figure 6: Estimated AODMR for Different Return Periods

5. Conclusion

Descriptive and statistical analysis of rainfall data for 1989–2018 was done to understand the rainfall pattern of the Botanical Gardens. The mean, standard deviation and coefficient of variation of yearly and monthly rainfall were determined to check the rainfall variability. From the calculated results, the rainfall pattern is found to be erratic. The greatest rainfall of 3536 mm occurred in 2008, followed by 3,315.50 mm in 2005 while the minimum rainfall of 1,592.20 mm occurred in 2001, and average annual rainfall for the 30 year period is 2339.3 mm. An analysis of the average monthly rainfall data for the Botanical Gardens for the period 1989 to 2018 shows a bi-modal yearly rainfall pattern. The highest mean rainfall value is in June (312.14 mm) and the least is in October (73.70 mm). Generally, a high variability is noted in the monthly rainfall data, with the month of March showing the highest variability (108%). The maximum value of one day maximum daily rainfall for the period was 210.2 mm and was recorded on July 15, 2015 and a least value of 68 mm was recorded July 08, 2003. The average one day maximum for the period was 109.69 mm.

Chegodayev technique provides a maximum rainfall that is about 99.7% of the average maximum rainfall, making it the best fit distribution for yearly rainfall data using the plotting position method, whilst the Gumbel's Extreme Distribution yields the highest value for rainfall for various return periods using the probabilistic methods. Chegodayev method is also the best fit for the AODMR. The estimated return period for the maximum AODMR value of 210.2 mm is 31 years. For accurate work Gumbel's extreme value distribution and Log-Pearson Type-III Distribution are the most widely used in hydrological and meteorological analyses for extreme values.

Urban engineers, farmers, and planners of water resources will all benefit from the knowledge provided by this research which would assist them in determining the availability of water and design the appropriate storage. For instance, given the very unpredictable rainfall pattern, good drainage systems in areas where they do not already exist can be properly designed which aid will avoid flooding, assist in agricultural stabilization and also offer farmers security when making long-term investments. Studies of this kind can also aid in a better understanding of climate and rainfall patterns on a regional and global scale.

Once adequate data becomes available, it is recommended that similar studies be performed for other coastal stations, as well as studies on storm duration (short and long) and intensity. Short duration storms with higher intensities, as opposed to longer storms with higher constant loading, can have different effects on drainage systems.

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