DETERMINING THE RAINFALL INDICES EXPECTED IN A RETURN PERIOD FOR THE REGION OF GUARATINGUETÁ – SP - BRAZIL

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The purpose of this article is to subsidize planning management of water resources, and the exploitation of water in various sectors, as well as serve as a reference for civil construction and climate studies. The used and properly compiled meteorological data were obtained from the Aeronautics Ministry Meteorological Station of São Paulo and the National Institute for Space Research. The data were analyzed according to the Gumbel distribution/methodology. The study was performed by not only addressing the overall period, but also the period in decades (period between 1974 - 2012), and the seasonal period (period between 1962 - 1991).

INTRODUCTION

The State of São Paulo, which has a total area of 248,210 km², represents 26.85% of the Southeast region and 2.91% of the Brazilian territory. The Guaratinguetá region presents a rainfall distribution influenced by frontal systems, orography, convective rains, as well as continental and sea breezes, making it a highly productive state at a national level. Studies developed by SILVA (1999) showed that the Guaratinguetá region presents an average annual rainfall distribution ranging from 1150 to 1750 mm, with a mean of 1450 mm.

The atmospheric precipitation, constituent of the hydrological cycle is influenced by physical, topographic, geological, and climate characteristics, contributing directly to the water balance. (Amorim, Ranieri Carlos F., 2002).

Cases such as landslides, falling buildings due to excessive rainfall, floods caused by rainfall excesses, as well as drought, cause malaise to the population and can be avoided with due monitoring of the risks involved in the problem. One of these risks is rainfall, which can be predicted through the use of return period probability, which is the average time (measured in years), used to analyze the project of a construction, with the objective of evaluating the probability of rainfall that can be equaled or even surpassed foor a certain period. This is necessary in the formulation of a project so that it can withstand this rainfall variation.

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OBJECTIVE

The objective of this work is to study the determination of the period of return or period of recurrence of rainfall totals through Gumbel distribution, aiming at improving activities that depend on the use of water in the region, thus improving the quality of life of the population.

MATERIALS AND METHODS

The present study was conducted in Guaratinguetá - SP - Brazil (latitude 22° 45' S, longitude 45°10'W, altitude of 536m). The used and properly compiled meteorological data were obtained from the Aeronautics Ministry Meteorological Station, the Department of Water and Energy of the State of São Paulo and the National Institute for Space Research. Return periods were determined using annual totals. The analysis was developed through excel software, using tables, functions and graphs. The adjustment of the series of annual precipitation values according to the normal curve performed through the graphs was to normalize the line through the least squares method in which the normal distribution is presented as a line passing through three characteristic points, whose distribution functions: F (UT) = 15,87%; F (U) = 50.0%; F (U + T) = 84.13%, where U is the mean and T is the standard deviation (VILELA & MATTOS, 1975).

It is noted that when the series of annual rainfall observations is quite long, the division of frequencies fits well with Gauss's law, so long as the elements of the series are considered without order of succession. Thus, the distribution function of Gauss's Law is expressed by:

$$F(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-z^2/2} dz$$

z: Is the reduced variable of the normal distribution, $z = \frac{x-m}{s}$.

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - m)^2}{n-1}}$$

F(x): probability of an annual total being less than or equal to x;
x: a determined annual total precipitation;

a-) The normal distribution is presented as a line that passes through three characteristic points:

1. $F(\mu) = 50$
2. $F(\mu - \sigma) = 15{,}87$
3. $F(\mu + \sigma) = 84{,}13$

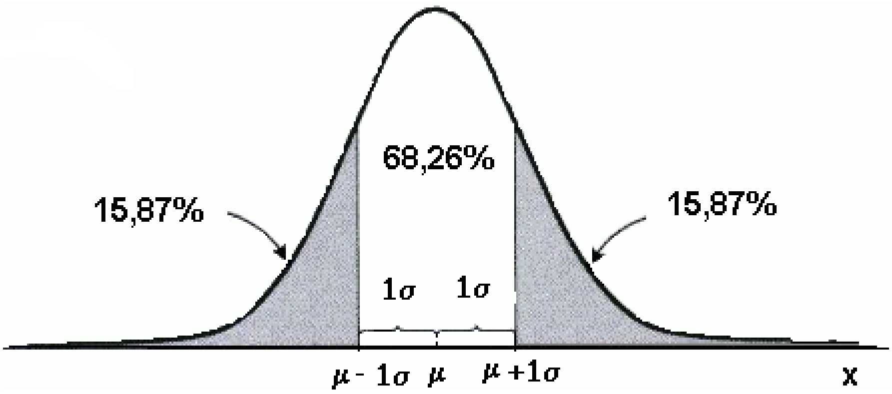
b-) Return periods are defined by:

1. $T = \frac{1}{F(x)}$, para $F(x) \leq 0{,}5$

2. $T = \frac{1}{1-F(x)}$, para $F(x) > 0{,}5$

c-) To analyze that F (x) satisfies the integral of the normal curve of probability distribution, as shown in Figure 6. This same image shows that the curve is symmetrical about the mean, knowing F (x), to be calculated [1-F (x)].

Figure 1: Gauss curve.



Source: UFPA

d-) Through this normal curve, the expected maximum and minimum rainfall (probabilities) are calculated for a given return period. The frequency distribution as a Function of the Return Period is shown in the following table:

Table 1: Breakdown of Frequencies as a Function of the Return Period.

	Probabilities of Expected Rainfall Heights	
Return Period	**Maximum**	**Minimum**
2 years	50%	50%
5 years	80%	20%
10 years	90%	10%
20 years	95%	5%
50 years	98%	2%
100 years	99%	1%
1.000 years	99,90%	0,10%
10.000 years	99,99%	0,01%

Source: Villela e Matos, 1975.

e-) The statistical analysis of the stations of the Guaratinguetá region were made through the annual totals from 1974 to 2012, grouping them in intervals of 20 mm of amplitude.

f-) The results were obtained directly via the Excel worksheet and will be presented and discussed below.

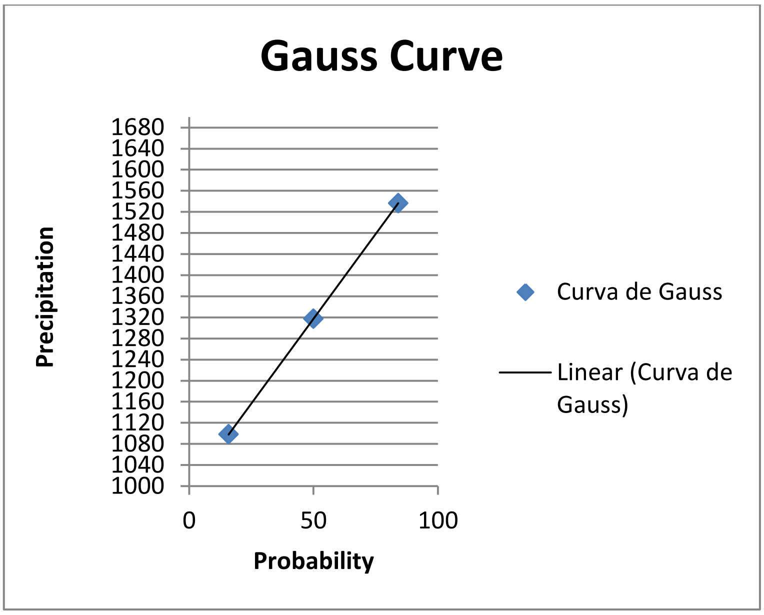
RESULTS AND DISCUSSION

Initially the annual rainfall study was carried out from 1974 to 2012 with an amplitude of 20 mm, thus having sixty study classes. It is observed that for the data of this period, the driest year was 1984 with 841.2 mm and the wettest year was 1976 with 2027.7 mm.

When the data were executed, a mean rainfall of 1317.18 mm was obtained, with a standard deviation of 219.13 mm, belonging to the average annual rainfall distribution of the region.

With the results obtained from the spreadsheet, the Gauss curve is constructed by linear trend, thus it is possible to evaluate the return period.

Figure 2. Construction of a linear trend through the mean and (mean ± standard deviation).



The graphs plotting points, in addition to the average that represents fifty percent probability of occurrence, are:

- X_1 = 1317,179 – 219,131 = 1098,05 (15, 87 %)

- X_2 = 1317,179 + 219,131 = 1536,31 (84,13%)

Using the Excel Prediction function, it was possible to get the data for the payback period below.

Table 2. Return period for the period from 1974 to 2012.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	1317,179	1317,179
5	80	20	1509,794	1124,564
10	90	10	1573,999	1060,359
20	94	6	1599,681	1034,677
50	98	2	1625,363	1008,995
100	99	1	1631,783	1002,575

Table 2 indicates that if the construction was designed for a 100-year return period, it should be said that the expected rainfall is 1% likely to occur in each year. The choice of the return period will depend on the construction, the most economically and socially viable solution, as well as the guidelines of each municipality.

It is also analyzed that 46% of the years were above the rainfall average, being able to demonstrate a good distribution of the precipitations during the period. However, in order to establish a good distribution, as well as possible climatic changes that may occur in the period of thirty-eight years, a more detailed analysis is necessary, for which a study was also carried out for decades and climatic seasons.

The first decade represents the years 1974 to 1983, the year of 1976 being the one with the highest rainfall index (2027.7 mm) and the year of 1980 with the lowest index with 1039.1 mm. The study was carried out with a data amplitude of 20 mm and thus obtaining 52 classes of study.

The average rainfall was 1304.00 mm, with a standard deviation of 144,653 mm. The relatively low standard deviation indicates that for the period there were not many exorbitant differences, which can be verified knowing that only 30% of the rainfall averages of the period are above the average and the biggest difference obtained between one year and the average is 723 mm.

The Gauss curve and the return period are thus constructed.

The graphic points, besides the average rainfall of the period are:

- X_1 = 1304, 00 – 144,653= 1159,35 (15, 87 %)

- X_2 = 1304, 00 + 144,653= 1448,65 (84,13%)

The period of recurrence of the first decade is of great importance since it can be evaluated later with the occurrence of the values of maximum and minimum predicted by the probabilities of rainfall heights for the following decades.

Figure 3 - Gauss curve through the linear trend of the Period from 1974 to 1983.

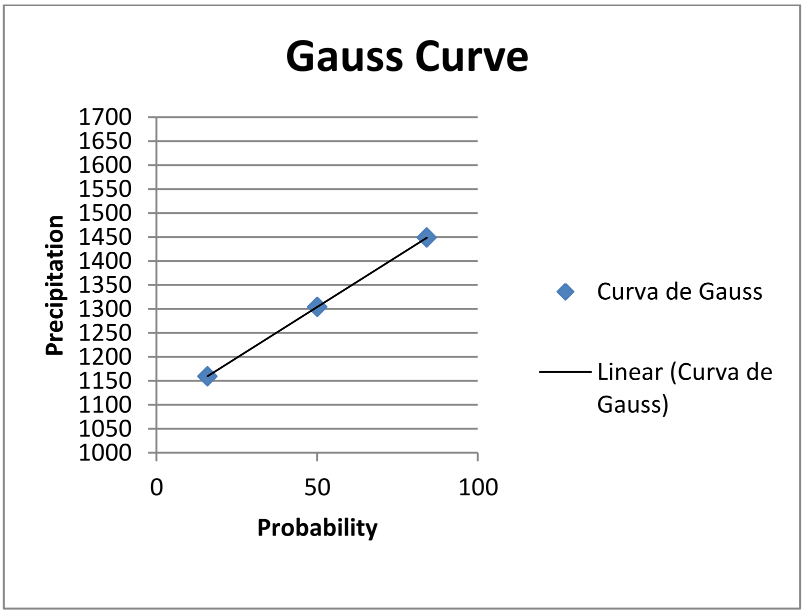


Table 3. Return Period from 1974 to 1983.

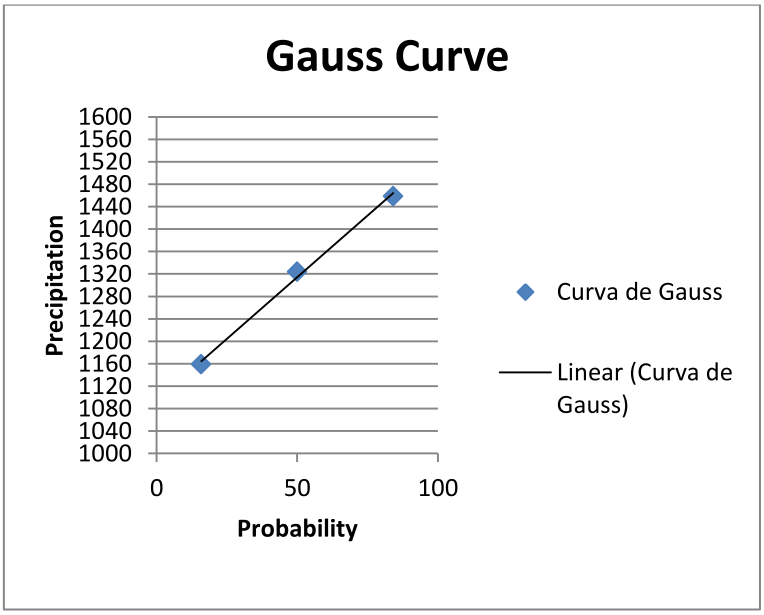
Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	1304,00	1304,00
5	80	20	1431,146	1176,854
10	90	10	1473,528	1134,472
20	94	6	1490,481	1117,519
50	98	2	1507,434	1100,566
100	99	1	1511,672	1096,328

The second decade represents the period from 1984 to 1993, with an amplitude of 20 mm and thirty eight classes of study. The average rainfall was 1324.00 mm with a standard deviation of 134.746 mm. It is worth noting that the data obtained are very close to the previous period, showing a homogeneous distribution of rainfall, with a lower standard deviation, with 50% of the data above the average, the wettest year being 1983, with 1573.7 mm and the driest being 1974 with 841.2 mm.
The Gauss curve and the Return Period are then constructed.
The graphic points beyond the rainfall mean of the period are:

- X_1 = 1324,00 – 134,746 = 1189,25 (15, 87 %)

- X_2 = 1324,00 + 134,746 = 1458,75 (84,13%)

Figure 4. Gauss curve with linear trend for the period from 1984 to 1993.



The graph points beyond the rainfall mean of the period are:

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Table 4. Recurrence Period from 1984 to 1993.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	1314,00	1314,00
5	80	20	1445,629	1182,371
10	90	10	1489,505	1138,495
20	94	6	1507,056	1120,944
50	98	2	1524,607	1103,393
100	99	1	1528,994	1099,006

Comparing the previous return period - the first decade - with the current one, it is verified that for a period of ten years the chance to occur the maximum rainfall of 1473.528 mm and the minimum of 1134.472 mm was of 10%, however it can be perceived that in the second decade, that is to say after ten years, the maximum was 1573.7 mm (1993) - higher than expected - and the minimum was 841.2 mm (1984), lower than expected. With this, it can be emphasized that the choice of a return period of 100 years or more is safer for a construction, since it covers a greater rainfall difference.

The third decade, comprising the years from 1994 to 2003, was studied with an amplitude of 20 mm, containing forty study classes. The minimum of this period occurred in 1994, with 937.4 mm of rainfall, and the maximum was in the year 2000 with 1713.6 mm.

The mean of the period was 1318.00 mm, with a standard deviation of 107.22 mm, presenting four years with above-average rainfall.

The Gaussian curve and the return period follow.

The points of the curve, besides the average of the period representing fifty percent, are:

- X_1 = 1318,00 – 107,22 =1210,78 (15, 87 %)

- X_2 = 1318 + 107,22 = 1425,22 (84,13%)

Figure 5. Gaussian curve with a linear trend for the period from 1994 to 2003.

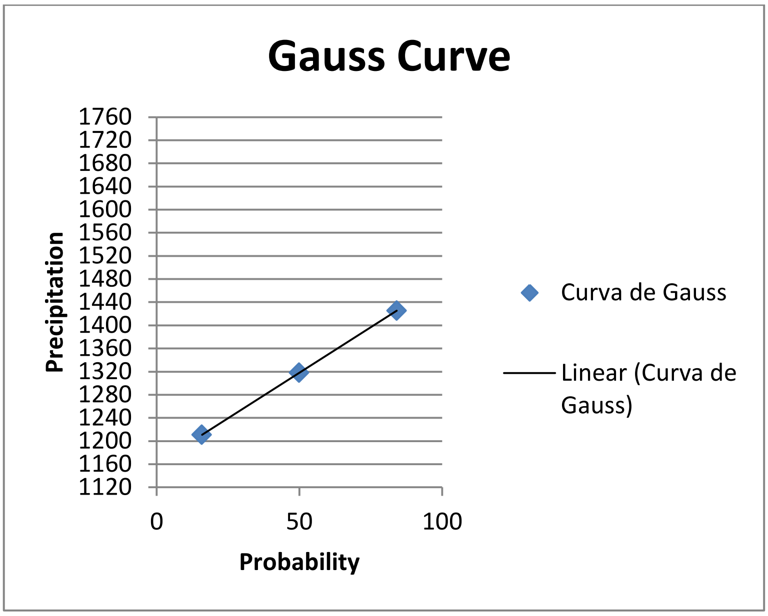

Table 5. Return period for the years 1994 to 2003.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	1318	1318
5	80	20	1412,237	1223,763
10	90	10	1443,649	1192,351
20	94	6	1456,214	1179,786
50	98	2	1468,779	1167,221
100	99	1	1471,92	1164,08

The fourth period studied, comprises the years 2004 to 2012, extending differently from the others, since it contains nine years and not ten. It was performed with a magnitude of 20 mm, thus obtaining twenty-three study classes, demonstrating a lower distribution of values in relation to the other periods, which contains at least thirty-eight classes.
The average rainfall is 1323.33 mm with a standard deviation of 84.55 mm, again reinforcing a smaller distribution of values in relation to the mean. The maximum value of rainfall heights was 1596.4 in 2005 and the minimum value was 1147.6 mm.
Below is the Gaussian curve and the table with the values of the period of return of the interval in question.
The points belonging to the curve, besides the rainfall mean are:

- X_1 = 1323,33 – 84,65 = 1238,68 mm (15, 87 %)

- X_2 = 1323,33 + 84,65 = 1407,98 mm (84,13%)

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Figure 6. Gaussian curve for the interval from 2004 to 2012.

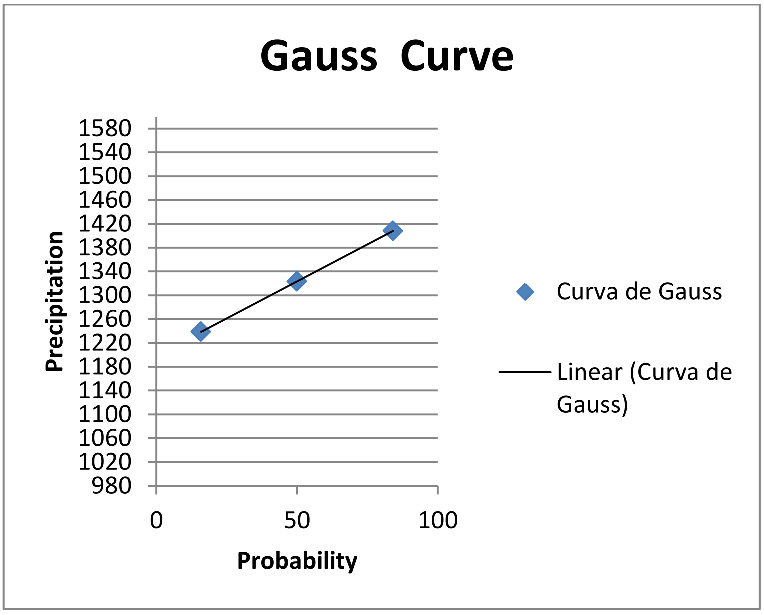

Table 6. Recurrence Period for the years 2004 to 2012.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	1323,33	1323,33
5	80	20	1397,737	1248,923
10	90	10	1422,539	1224,121
20	94	6	1432,46	1214,20
50	98	2	1442,381	1204,279
100	99	1	1444,861	1201,799

In addition to the analysis of the interval from 1974 to 2012 in decades, the detail was also analyzed in relation to the seasons, with the difference in relation to the period covered, the second detail being from 1962 to 1991.

The second particularization becomes important in the search for the difference in relation to the average of the interval studied, that is, in which season a greater difference was obtained in relation to the average, and also, in the study of verification according to the local climate. The first season of the year studied was the summer, with thirty study classes of amplitude 20 mm. It had a high rainfall index in 1985 with 866.1 mm and low in 1984, with 282.2 mm. It obtained a rainfall of 616.00 mm and a standard deviation of 209.11. These figures demonstrate how much the year of 1984 was relatively dry, and that soon after a dry summer, a rainy season was achieved in 1985. The points referring to the linear trend of the graph, besides the average, are:

- X_1 = 616,00 – 209,11 = 406, 89 (15, 87 %)

- X_2 = 616,00 + 209,11 = 825,11 (84,13%)

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Figure 7. Gauss's curve for summer rainfall averages obtained from 1962 to 1991.

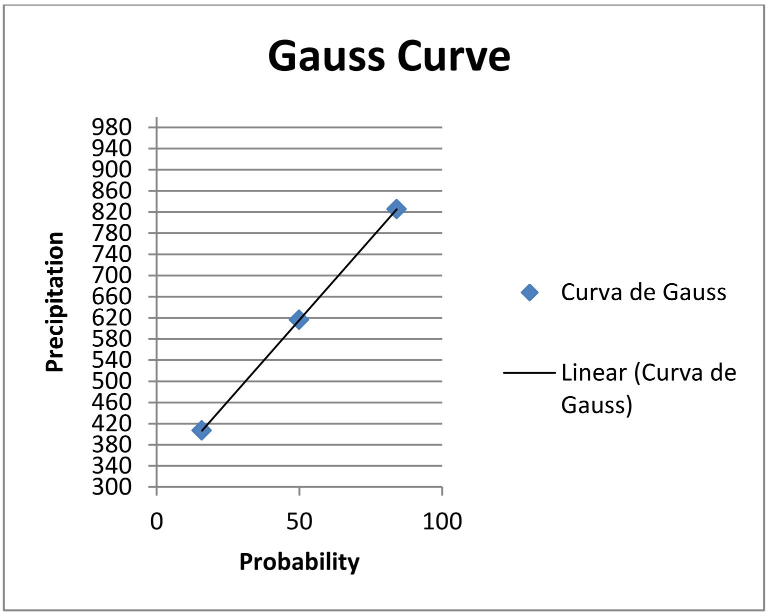

Table 7. Return Period - Summer - 1962 to 1991.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	616,00	616,00
5	80	20	799,81	432,19
10	90	10	861,07	370,93
20	94	6	885,58	346,42
50	98	2	910,09	321,91
100	99	1	916,22	315,78

The second season of the year studied was autumn, with 20 mm of amplitude and twenty-eight classes. The year of 1987 had the maximum rainfall of 558.4 mm and the year of 1963 the minimum of 7.4 mm, totally dry period.
It had a rainfall of 158.00 mm and a standard deviation of 127.48 mm, presenting an average well below that obtained in summer.
The Gaussian curve and return period are shown below.
The points of the Gaussian curve, besides the pluviometric average, are:

- X_1 = 158 – 127,48 = 30,52 (15, 87 %)

- X_2 = 158 + 127,48 = 285,48 (84,13%)

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Figure 8. Gauss curve for the pluviometric means of Autumn obtained from 1962 to 1991.

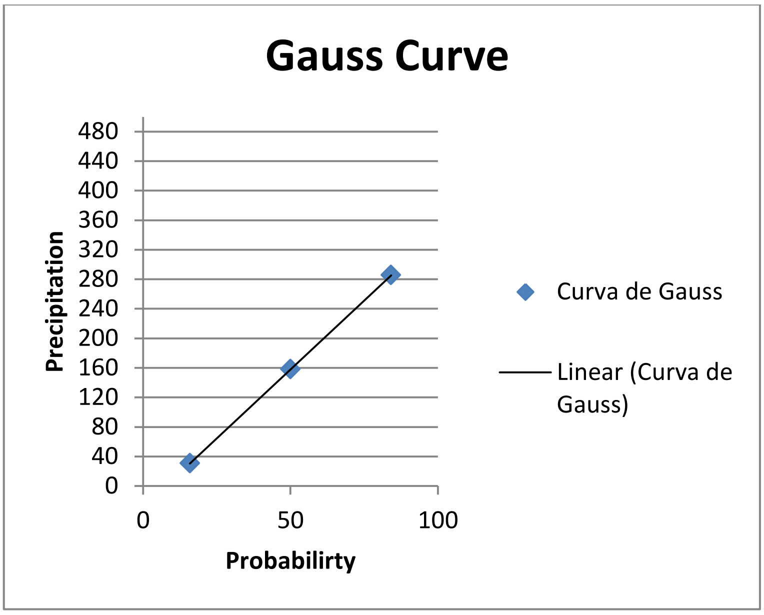

Table 8. Return Period - Autumn - 1962 to 1991.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	158,00	158,00
5	80	20	270,05	45,95
10	90	10	307,41	8,59
20	94	6	322,35	0,00
50	98	2	337,29	0,00
100	99	1	341,02	0,00

The third station studied was winter, with an amplitude of 10 mm, obtaining thirty-four study classes. The year of 1963, as in the autumn, presented the lowest rainfall, with 8.1 mm, being higher than that obtained in autumn, and the year of 1976 with 346.8 mm.

The mean of the period was 123.67 mm with a standard deviation of 80.03 mm, corresponding to the driest season of the year.

The Gaussian curve and the return period obtained are below.

The points of the Gaussian curve, besides the pluviometric average, are:

- X_1 = 123,67 – 80,03 = 43,64 (15, 87 %)

- X_2 = 124,67 + 80,03 = 203,7 (84,13%)

Figure 9. The Gauss curve for winter pluviometric means obtained from 1962 to 1991.

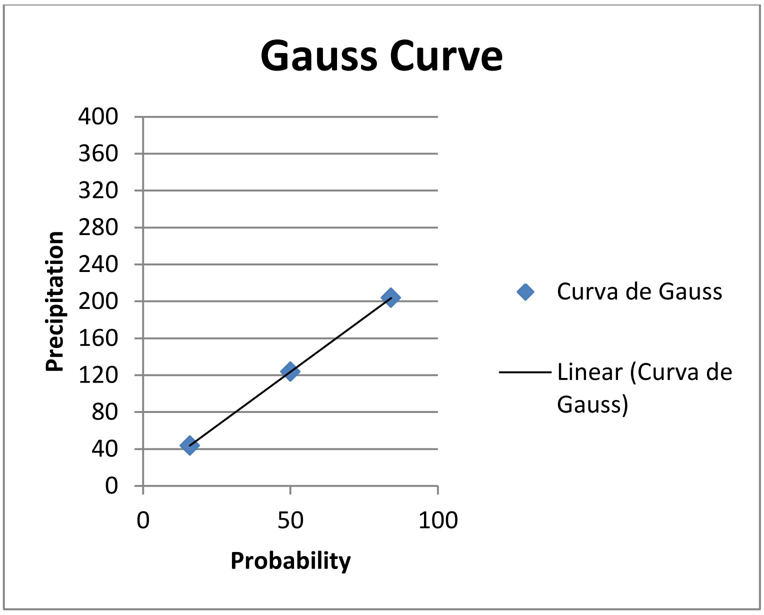

Table 9. Return Period - Winter - 1962 to 1991.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	123,67	123,67
5	80	20	194,02	53,32
10	90	10	217,46	29,88
20	94	6	226,84	20,50
50	98	2	236,22	11,12
100	99	1	238,57	8,77

The fourth and last season of the year studied was spring, with an amplitude of 20 mm and twenty-two study classes. The maximum obtained was in 1991 with 762.9 mm and the minimum in 333.9 mm in 1990, occurring the same as in summer, a drier spring followed by a more humid spring.
The spring mean was 502.00 mm and 192.44 mm was the standard deviation, with the second season being rainier.
We have the Gaussian Curve and the Period of Return.
The points of the Gaussian curve, besides the pluviometric average, are:

- X_1 = 502 – 142,94 = 359,06 (15, 87 %)

- X_2 = 502 + 142,94 = 644,94 (84,13%)

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Figure 10. Gauss curve for spring rainfall averages obtained from 1962 to 1991.

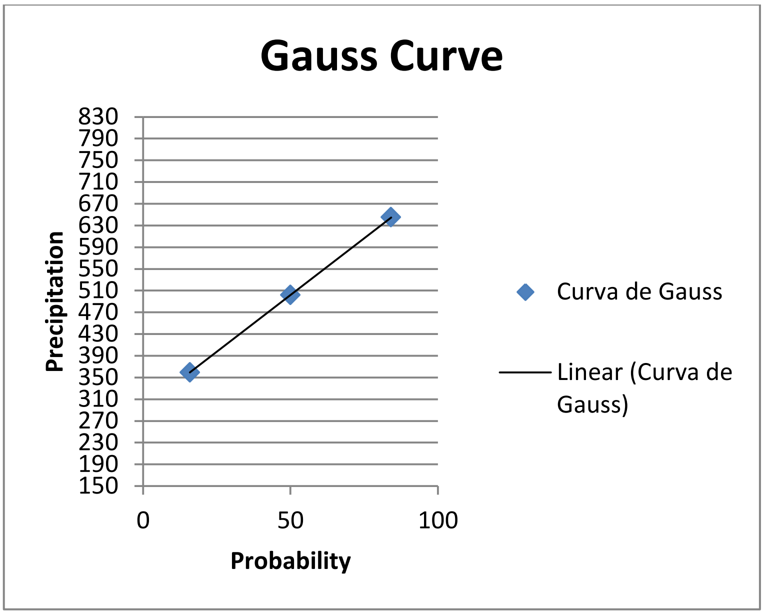

Table 10. Return Period - Spring - 1962 to 1991.

Return Period (years)	Probability of rainfall heights (%)		Precipitation (mm)	
	Max.	Min.	Max.	Min.
2	50	50	502,00	502,00
5	80	20	627,64	376,36
10	90	10	669,52	334,48
20	94	6	686,28	317,72
50	98	2	703,03	300,97
100	99	1	707,22	296,78

CONCLUSION

The period of return or recurrence becomes important in the analysis of the project of a construction, to the point that makes the probability of rain that can be equaled or even surpassed for a certain period possible. In the present study, the knowledge was destined for the city of Guaratinguetá - SP.

It is observed through the data obtained in the first detail - for decades - that they behave throughout the season with rainfall distribution in a homogeneous way, obtaining rainfall averages for decades that do not distance 20 mm, nevertheless, present increasing averages over Decades.

The interval also presented rainfall averages that, after a high rainfall, had a decrease in rainfall in the following year or decreases over a period of years, until reaching a low rainfall and increasing again, showing a cyclic distribution pro period.

In relation to the return period, we analyze the relationship between the maximum and minimum amount predicted for each time period, in Table 11, these values follow with the percentage of years that exceeds the maximum / minimum predicted in relation to the period Indicated. For example, the 10-year return period from 1974 to 1983 provided for a maximum rainfall of 1473,528 as well as a minimum of 1134, 472 but 40% of the rainfall for the period 1984 to 1993 exceeded the forecast maximum while the Minimum is within the forecast.
All indicate a better predicted value according to the increase of the return period. This indicates, that as far as works are concerned, the safety range of its construction is as great as its period of return, despite the need for more funds at th same time.

Table 11. Comparison between return period

Return Period	1974-1983	1984-1993	1994-2003	2004-2012
10 Years	Max. 1473,528 40% Mín.1134,472 10%	Max.1489,505 20% Mín.1138,495 20%	Max.1443,649 20% Mín.1192,351 20%	Max.1422,539 Mín.1224,121
20 Years	Max.1490,481 20% Mín.1117,519 20%	Max.1507,056 10% Mín.1120,944 0%	Max.1456,214 Mín.1179,786	Max.1432,46 Mín.1214,20
100Years	Max.1511,672 Mín.1096,328	Max.1528,994 Mín.1099,006	Max.1471,92 Mín.1164,08	Max.1444,861 Mín.1201,799

In the second detail, done through the seasons, the averages behave according to the season for the tropical climate of altitude, with summer being more rainy, followed by spring, autumn and winter being the driest one, with a difference of average rainfall between summer and winter of 492.33 mm. Thus, there are lower return periods in winter and autumn than in spring and summer. It is noteworthy that for autumn there is a 20% probability of not raining during the fall period, that although the averages are larger than that of the winter, the minimum forecast for winter is 8.77 mm.

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