EVALUATION OF WIND ENERGY POTENTIAL AND ESTIMATION OF COST USING WIND ENERGY TURBINES FOR ELECTRICITY GENERATION IN NORTHERN CYPRUS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
ABDELRAHMAN M. S. ALGHAZALI

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

NICOSIA, 2018

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Approval of Director of Graduate School of

Applied Sciences

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We certify this thesis is satisfactory for the award of the degree of Master of Science in Mechanical Engineering

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I hereby declare that, all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name:

Signature:

Date:

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From the beginning of my journey in Near East University until this day, Assist. Prof. Dr. Hüseyin ÇAMUR, the godfather of Mechanical Engineering Department’s students, and Dr. Youssef KASSEM, my mentor and first advisor, were the most helpful and supportive people I met. Their endless encouragement and advises was the main cause of this study completion, they believed in me since day one, for all that, words are powerless to express my gratitude to both of you, Thanks a lot.

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To my beloved family and my lovely girlfriend, I am so thankful for your support, I would have never reach to this point without you, and I greatly appreciate you all.

To Palestine, with love…

ABSTRACT

In this thesis, a data of 17 years of average monthly wind speed were used to establish a full evaluation of the potential of wind energy in Northern Cyprus at six different locations, namely; Dipkarpaz, Ercan, Gazimağusa, Girne, Güzelyurt and Lefkoşa using Weibull distribution function. Starting with an overview of the current situation of the energy sector of Northern Cyprus, after that, the thesis presented an inclusive literature review of the studies in wind energy potential and economics of wind energy, followed by an investigation of the mathematical model applied in wind potential studies. Then, a preview of the economic analysis method has been presented. Next, the description of the selected location and the data sources along with the methodology pursued was given. In the result part, the wind speed monthly, seasonally and annually variations has been analyzed, the performance of selected wind turbines in all locations investigated and cost using PVC method of analysis for each turbine are provided. The results showed that, Average yearly Weibull wind power density is found to be the highest in Dipkarpaz with a value equal to 46 kW/m2 followed by Gazimağusa with a mean value of 37.8 kW/m2, Ercan comes third 29.8 kW/m2, Lefkoşa, Girne and Güzelyurt have a low average wind power density with a values equal to 10.8, 10.9 and 11 kW/m2, respectively. The most suitable location for electricity generating by wind energy was found to be Gazimağusa using Enercon E33 wind turbine with capacity factor equals 35% and cost per kW h equal 0.00027 US$/kW h.

Keywords: Wind energy potential; Weibull distribution function; capacity factor; wind turbine; present value cost PVC

ÖZET

Bu tezde, Kuzey Kıbrıs'ta rüzgar enerji potansiyelini tam anlamıyla değerlendirebilmek için altı farklı bölgede 17 yıl boyunca kaydedilmiş aylık ortalama rüzgar hızı verileri kullanılmıştır. Weibull dağıtım fonksiyonunu kullanarak Dipkarpaz, Ercan, Gazimağusa, Girne, Güzelyurt ve Lefkoşa'da ilgili veriler değerlendirilmiştir. Bu tezde Kuzey Kıbrıs'ın enerji sektörünün mevcut durumuna genel bir bakış ile başlayarak, rüzgar enerjisi potansiyeli ve rüzgar enerjisi ekonomisinde yapılan çalışmalarla ilgili literatür taraması yapılmış, rüzgar potansiyeli çalışmalarında uygulanan matematiksel model araştırılmıştır. Daha sonra, ekonomik analiz yöntemi sunulmuş ve bunun ardından, seçilen konumun açıklaması ve takip edilen metodoloji ile birlikte veri kaynakları verilmiştir. Sonuç bölümünde, aylık, mevsimsel ve yıllık değişimlerdeki rüzgar hızı analiz edilmiş, her bir türbin için incelenen tüm rüzgar türbinlerinin performansları ve PVC analiz metodu kullanılarak maliyetlendirilmiştir. Sonuçlar, yıllık ortalama Weibull rüzgar enerjisi yoğunluğunun 46 kW/m^2'lik bir değerle en fazla Dipkarpaz'da olduğunu göstermiştir. Dipkarpaz'ı 37.8 kW/m^2'lik bir ortalama değerle Gazimağusa izlemiş, Ercan ise 29.8 kW/m2 ile üçüncü sırada yer almıştır. Lefkoşa, Girne ve Güzelyurt bölgelerinin sırası ile 10.8, 10.9 and 11 kW/m2'lik değerler ile düşük ortalama rüzgar enerjisi yoğunluğuna sahip oldukları tespit edilmiştir. Rüzgar enerjisi ile elektrik üretimi için en uygun yer Gazimağusa bölgesi tespit edilmiştir. Bü üretim için 35.3% kapasite faktörüne sahip Enercon E33 rüzgar türbini kullanılmış ve kW h başına birim maliyeti 0.00027 US$/kW olarak belirlenmiştir.

Anahtar Kelimeler: Rüzgar enerjisi potansiyeli; Weibull dağıtım fonsiyonu; kapasite faktörü; rüzgar türbini; bugünkü değer maliyeti PVC

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LIST OF SYMBOLS USED

A	Rotor swept area, m^2
Btu	British thermal unit
$\boldsymbol{c}$	Scale factor, m/s
$\boldsymbol{C_{o\&m}}$	Operation and maintenance cost \$/kW
$\boldsymbol{C_f}$	Capacity factor, unit less
$\boldsymbol{E_{pf}}$	Energy pattern factor, unit less
$\boldsymbol{E_{out}}$	Total output energy, kW h
$\boldsymbol{h_1}$	Initial height, m
$\boldsymbol{h_2}$	Extrapolated height, m
I	Investment costs, \$
$\boldsymbol{i}$	Inflation rate, unit less
$\boldsymbol{k}$	Shape factor, unit less
n	Machine life, years
$\boldsymbol{P_r}$	Rated power, kW
$\boldsymbol{P_{w(i)}}$	Turbine's power curve, kW
r	Discount rate, unit less
S	Scrap value, unit less
$\boldsymbol{\alpha}$	Power law exponent, unit less
$\boldsymbol{\Gamma}$	Gamma function, m/s
$\boldsymbol{\lambda}$	Log location factor, m/s
$\boldsymbol{v_1}$	Measured speed, m/s
$\boldsymbol{v_2}$	Extrapolated speed, m/s
$\boldsymbol{v_{avg}}$	Average wind speed, m/s
$\boldsymbol{v_{in}}$	Cut-in wind speed, m/s
$\boldsymbol{v_o}$	Cut-out wind speed, m/s
$\boldsymbol{v_r}$	Rated wind speed
$\boldsymbol{\overline{v}}$	Mean wind speed, m/s
$\boldsymbol{\overline{v^3}}$	Mean of wind speed cubes, m/s
$\boldsymbol{\phi}$	Logistic scale, m/s

$\boldsymbol{\rho}$	Air density, kg/m^3
$\boldsymbol{\sigma}$	Standard deviation, m/s
$\boldsymbol{\omega}$	Weight factor, unit less

ABBREVIATIONS USED

ANFIS	Adaptive Neuro-Fuzzy Inference System
CDF	Cumulative Distribution Function
PDF	Probability Density Function
UCE	Cost per kW h of Electricity Generated
WPD_w	Weibull wind power density
WPD_G	Gamma wind power density

CHAPTER 1
INTRODUCTION

1.1 Overview

Wind is a clean, free and infinite energy source which has benefited mankind for numerous years and centuries, by powering sailing ships, windmills and pumping water (Johnson, 2006). At the present time, aiming for preventing environmental pollution and energy security also, the rising concerns over global warming, have guided into increasing in the interest of emerging renewables in energy production systems to create environmental friendly power generation system, such as solar, wind, hydrogen, hydropower, and geothermal. For providing an appropriate solution to the global climate change and energy crisis (Walker and Shinn, 2002). The importance of wind energy and other renewable energy sources will increase in coming years, due to an expected significant growth of energy need worldwide, therefore, it will not only be considered as a replacement of fossil fuels, it will be one of the most important sources of energy in future (Dupont et al., 2017). In 2012, the total consumption of the marketed energy was 549 quadrillion British thermal units (Btu), which will experience a remarkable expand to 629 quadrillion (Btu) in 2020, and an expected total consumption of 815 quadrillions (Btu) in 2040, 48% increase in consumption in 28 years (2012-2040) (International Energy Agency, 2017).

In the case of developing countries, which have around 80% of the world's population, they are consuming only 30% energy of the global market (Barakabitze et al., 2017).The economics of islands suffers from the limitation of natural resources, for that reason, tourism, education and other sectors of services are the main foundation of islands economics (Bergmann, 2006). In Northern Cyprus, the effect of population growth, the increasing numbers of students and tourists and the uprising life standards led to energy demand escalating by years, this demand increase caused a high dependency on imported fuel. Due to the energy supply cost increases, the limitation of storage capacity of oil and aiming to environmental preservation, Northern Cyprus needs to move towards renewable energy sources utilization (Solyali et al,. 2016).

1.2 An overview of Northern Cyprus's energy sector

This section provides an overview of the current state of northern Cyprus energy sector.

1.2.1 Electricity demand

Regarding the annual production of electricity and the peak demand in Northern Cyprus in the period of 30 years (1995-2025), the statistics indicate an average annual increase of the production by about 5.7% during the last 20 years. Between 1995 and 2014, the annual production jump from 527 up to 1374 GWh, While the peak demand in the same period increased from 100 MW to 279 MW, as shown in Figure 1.1, 1.2 and 1.3 (Grunwald, 2015).

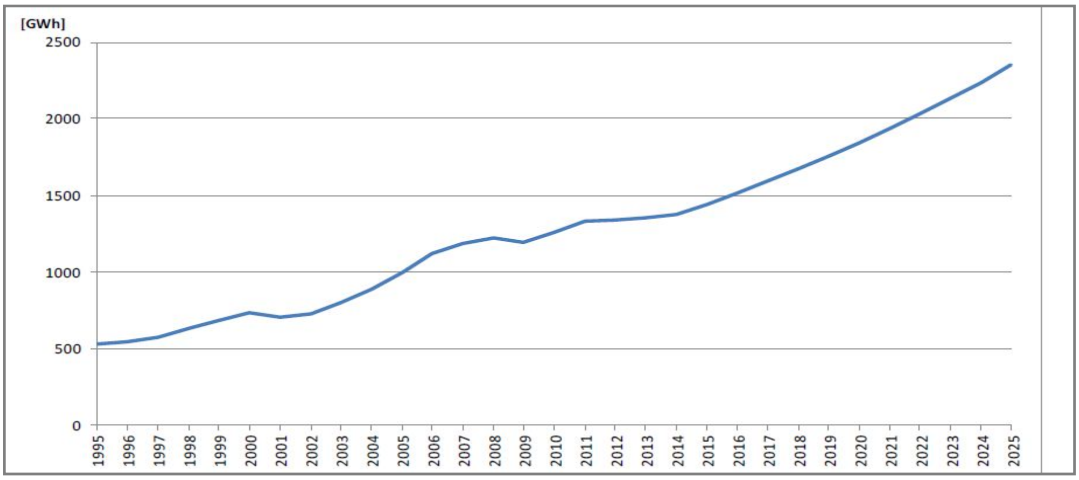

Figure 1.1: Development of annual electricity production (Grunwald, 2015)

Cyprus Turkish Electricity Corporation (kib-tek) has assumed an average growth rate of 5% per year between 2015- 2025, based on the past growth of electricity demand illustrated. Annual production will reach 2350 GWh and the peak demand will be 477 MW in 2025 with this growth rate. Figures1.4 and 1.5, shows the daily maximum and minimum loads in 2013 and the load duration curve for 2013, respectively (Grunwald, 2015).

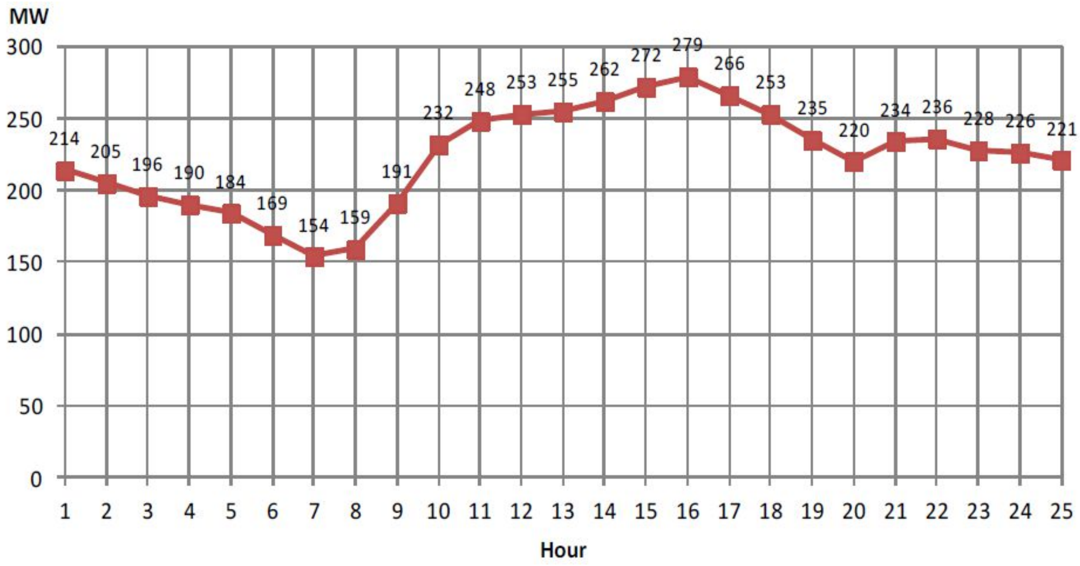

Figure 1.2: Daily load curve on 25 August 2014 (Grunwald, 2015)

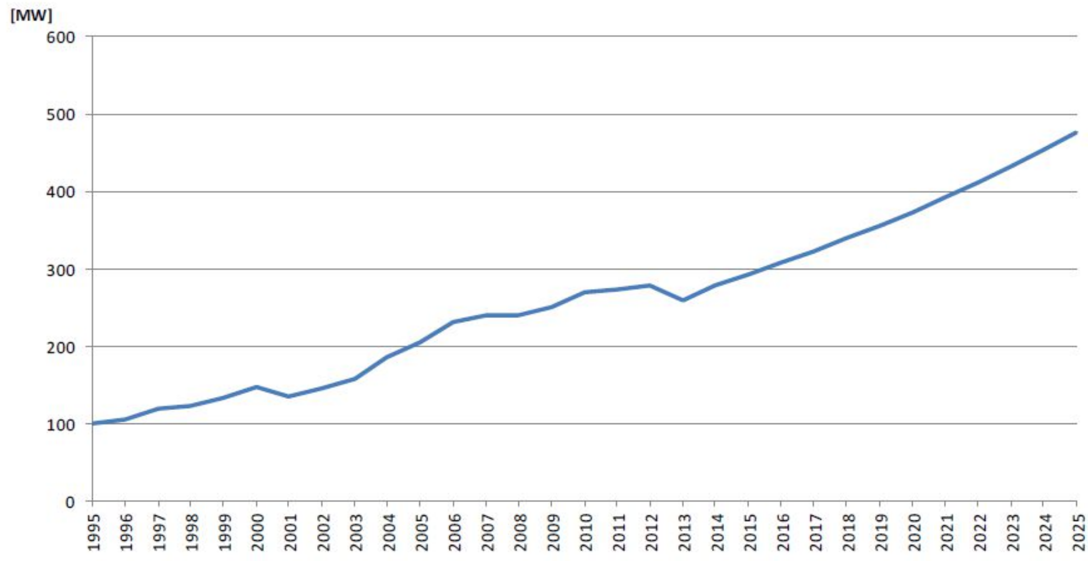

Figure 1.3: Development of annual peak load (Grunwald, 2015)

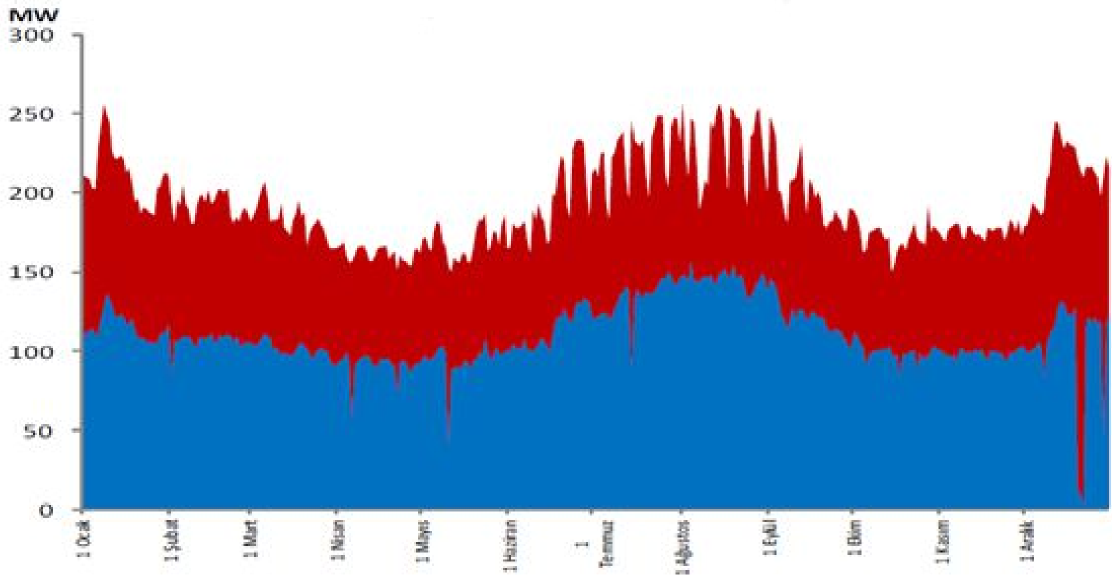

Figure 1.4: Minimum-maximum daily loads (Grunwald, 2015)

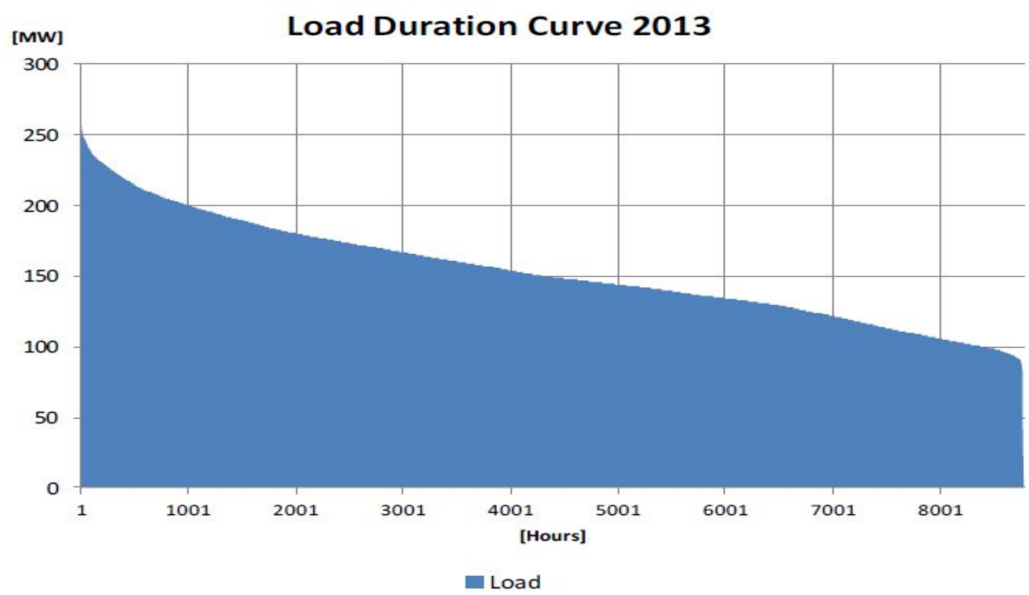

Figure 1.5: Curve of load duration for 2013 (Grunwald, 2015)

The previous figures showed that the annual demand will increase by about 6% every year, to cover this demand increase, all possible alternatives must be analyzed to be able to select the most appropriate one.

1.3 Aim of Thesis

This thesis aims to study, evaluate, analyze and answer the following research objectives for Northern Cyprus.

1. Wind characteristics (speed, direction and potential) at selected locations.
2. The behavior of wind speed with time (months, seasons and years).
3. How does wind speed changes with height at each location?
4. Best distribution function to evaluate the wind potential for the given data.
5. Which Locations offers the highest capacity factors and least cost?
6. The most appropriate wind turbine class for each location.
7. Is electricity generation by wind a good option or not for a given location?

1.4 Thesis Outline

The first chapter of the thesis presented a brief introduction about the wind energy as a renewable energy source and its importance as an alternative for the traditional electricity generation types like fossil-fueled power plants. And then describe the current status of the energy sector in Northern Cyprus and the expected development of the demand and supply in the coming years.

In chapter 2, literature research on wind energy potential, the economics of wind energy and on the previous studies conducted in Northern Cyprus regarding the wind potential.

The third chapter discussed the mathematical models used to evaluate the wind potential in literature; different models are presented and discussed in details.

Chapter 4 expressed the economic analysis methods and parameters of wind turbines and its classifications.

The methodology of the study is presented in chapter 5. Starting with the description of the sites under analysis and the data sources then, discussion of the models used for evaluating the wind potential and performance.

The results and discussion are presented in chapter 6, subsequently; chapter 7 provides the conclusions and recommendations.

CHAPTER 2
LITERATURE REVIEW

2.1 Recent Studies Concerning the Wind Energy Potential

In past years, several studies have been done regarding wind energy evaluation all around the world. In China, the onshore potential of wind energy was assessed by (Yi et al., 2018) for six sites under different climate conditions. It was concluded that Weibull distribution function fitted the measured wind speeds well and the best performance for estimating the Weibull parameters was exhibited by the moment method. Asghar and Liu (2018) used adaptive neuro-fuzzy methodology (ANFIS) to express the probability distribution of wind speed and the potential of wind energy. They compared the performance of ANFIS model with other numerical methods. The results indicate that for estimating the Weibull PDF accurately ANFIS sowed better results over all other methods. In Morocco, the potential of wind energy in six regions conducted by (Allouhi et al., 2017) for assisting the decision making for establishing a wind farm, after the analysis, two sites were considered to be suitable for grid-connected wind power system.

Mostafaeipour et al. (2014) evaluated the potential of wind energy in Zahedan city in Iran. It was reported that the maximum wind speed occurred at noon with an average of 5.25 m/s wind speed. And it is been proven that a small-scale wind turbine with 2.5 kW power rating is the most economical model. In Egypt, the characteristics of wind energy park installation have been studied by (Ahmed, 2018) in Shark El-Ouinat city. In September and December, the highest and lowest wind speeds were found to be 7.4 and 5.4 m/s, respectively. It is been reported that a wind farm with 150 MW capacity will provide an economically feasible electricity with 1.3 € cent/ kWh price.

Ammari et al. (2015) evaluated the wind potential in Jordan. Conclusions stated that at Aqaba Airport region, generating power from wind is a good option. Soulouknga et al. (2018) analyzed the data of wind speed in Chad using Weibull distribution and reported that wind energy is a good an alternative for the future in the Saharan zone. In Algeria, Belabes et al.(2015) used wind energy turbines to evaluate the potential of wind energy.

The study concluded that due to the high generation prices the northern part of the country, wind energy power generation is not recommended.

2.2 Studies on the Economics of Renewable Energy Sources

Khatib and Difiglio (2016) studied the economics of renewables and concluded that renewables are facing economic challenges; their cost is significantly higher than building fossil-fueled power plants but this cost is decreasing by years. Edenhofer et al. (2013) reviewed pivotal aspects of renewables economics, explored different community goals mitigating the deployment of renewables and estimated the economic potential of renewables. Adams et al. (2018) analyzed the effect of renewable and non-renewable energy consumption on economic growth in 30 African countries between 1980 and 2012 and observed that growth-enhancing effects of the non-renewable sources are higher than the renewables due to resent investment in renewables in those countries. In general, the capacity of renewables in African countries increased by 60% in last 15 years.

2.3 Wind Energy Potential Studies in Northern Cyprus

Solyali et al. (2016) presented a technical assessment of the potential of wind power in Northern Cyprus at Selvilitepe site. Calculated 207- 221-329 W/m^2 power densities at 30- 50- 90 m, respectively, with a mean wind speed of 5.11 m/s at 30 m and 5.96 m/s at 90 m. the data used to calculate this results was collected in the period of 8 years between 2007 and 2014.

CHAPTER 3
MATHEMATICAL MODEL

3.1 Methods for Estimation the Potential of Wind Energy

To evaluate the potential of wind energy in a region, knowing the distribution of wind speed is an essential factor. Using this knowledge, the technical and economic characteristics can be determined conveniently. Different functions have been used to characterize the distributions of wind speed frequency, in this section; brief explanations of these functions are offered.

3.1.1 Uni-modal functions

Weibull distribution

To present the distribution of wind speed and estimating the power density of wind Weibull distribution has been used frequently in the literature (Bilal et al., 2013). It presents a good match with measured data (Akdağ et al., 2010). The probability density function (PDF) of the wind speed is given by:

$$f(v) = \left(\frac{k}{c}\right).\left(\frac{v}{c}\right)^{k-1}.exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{3.1}$$

While the Cumulative Distribution Function (CDF) is given as:

$$F(v) = 1 - \exp\left(-\frac{v}{c}\right)^{k} \tag{3.2}$$

Where, c is the scale parameter, which has the same unit of speed, and k is the shape parameter, which is dimensionless and v is the speed of the wind.

Using the scale and shape parameters Weibull average wind power density (WPD_w) can be calculated by the following expression

$$WPD_w = \frac{1}{2}\,\rho\, c^3\Gamma\left(1+\frac{3}{k}\right) \tag{3.3}$$

Where, Γ is the Gamma Function.

Gamma distribution

Is one of the extensively used distribution functions in wind evaluation literature, because of its common properties with exponential and normal distributions (Belabes et al., 2015).

60 years ago, studies of wind speed statistically were performed using Gamma distribution and been considered as a discrete random variable (Sherlock, 1951).

Generalized Gamma distribution has found to be adequate to express the surface distribution of wind speed all around Europe (Kiss & Jánosi, 2008). It is given as

$$f(v) = \frac{v^{k-1}}{\Gamma(k).c^k} \exp\left(-\frac{v}{c}\right) \tag{3.4}$$

Gamma average wind power density (WPD_G) is expressed by

$$WPD_G = \frac{1}{2}\,\rho\, c^3\big(k(k+1)(k+2)\big) \tag{3.5}$$

Rayleigh distribution

Rayleigh distribution represents the case of fixing the value of shape factor of the Weibull distribution to 2. Rayleigh distribution PDF and CDF are given by the following equations respectively;

$$f(v) = \frac{\pi}{2}\left(\frac{v}{v_{avg}^2}\right) \exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{v_{avg}}\right)^2\right] \tag{3.6}$$

$$F(v) = 1 - \exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{v_{avg}}\right)^2\right] \tag{3.7}$$

Burr distribution

Or Singh-Maddala distribution, which has been applied to express the distribution of wind speed in some recent literature, can produce a good fit with the recorded data (Waal et al., 2004).

$$f(v) = \frac{akv^{a-1}}{c^a\left[1 + \left(\frac{v}{c}\right)^a\right]^{1+k}} \tag{3.8}$$

Lognormal distribution

Also known as the Galton distribution, is a probability distribution of the normally distributed logarithmic variables of wind speed (Allouhi et al., 2017). The PDF of this function can be determined from this equation;

$$f(v) = \frac{1}{c.v.\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{ln(v) - k}{c}\right)^2\right] \tag{3.9}$$

Truncated Normal distribution

Is a special case of the normal distribution which expressed as (Carta et al., 2009):

$$f(v) = \frac{1}{\mathrm{I(k,c).c.}\ \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{v - k}{c}\right)^2\right] \tag{3.10}$$

Where I (k, c) is given by:

$$f(v) = \frac{1}{\mathrm{c}\sqrt{2\pi}} \int_0^\infty \exp\left[-\frac{1}{2}\left(\frac{v - k}{c}\right)^2\right] dx \tag{3.11}$$

Log-logistic distribution function

Is a function used to distribute the logistic form logarithmic variables of wind speed (Alavi et al., 2016). It is given by

$$f(v) = \frac{\exp\left(\frac{ln(v) - \lambda}{\phi}\right)}{\phi.v.\left[1 + \exp\left(\frac{ln(v) - \lambda}{\phi}\right)\right]^2} \tag{3.12}$$

Where, ϕ and λ are logistic scale and log location parameter, respectively.

Inverse Gaussian distribution

In the case of low frequencies and speeds, this function can be considered as an alternative to the three-parameter Weibull distribution (Bardsley, 1980). It is written as:

$$f(v) = \left(\frac{k}{2\pi v^3}\right)^{\frac{1}{2}} . \exp\left[-\frac{k(v - c)^2}{2vc^2}\right] \tag{3.13}$$

3.1.2 Multimodal distributions

Weibull-Weibull distribution function

Various literature draw attention for this function (José Antonio Carta and Ramírez, 2007), it is expressed as

$$f(v) = \omega\left[\left(\frac{k_1}{c_1}\right).\left(\frac{v}{c_1}\right)^{k_1-1}.\exp\left[-\left(\frac{v}{c_1}\right)^{k_1}\right]\right] + (1-\omega)\left[\left(\frac{k_2}{c_2}\right).\left(\frac{v}{c_2}\right)^{k_2-1}.\exp\left[-\left(\frac{v}{c_2}\right)^{k_2}\right]\right] \quad (3.14)$$

Where, ω is the weight factor which denotes to the proportion of the distribution.

Gamma-Weibull distribution function

Combination of Gamma and Weibull functions that is originally applied in wind energy assessment is given by (Chang, 2011);

$$f(v) = \omega\left[\frac{v^{k_1-1}}{\Gamma(k_1).{c_1}^{k_1}}\exp\left(-\frac{v}{c_1}\right)\right] + (1-\omega)\left[\left(\frac{k_2}{c_2}\right).\left(\frac{v}{c_2}\right)^{k_2-1}.\exp\left[-\left(\frac{v}{c_2}\right)^{k_2}\right]\right] \quad (3.15)$$

Truncated normal-Weibull distribution

A mix of truncated Weibull and truncated normal distribution can be expressed by (Akpinar & Akpinar, 2009)

$$f(v) = \omega\left[\frac{1}{I(k_{1,}c_1)c_1.\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{v-k_1}{c_1}\right)^2\right]\right] + (1-\omega)\left[\left(\frac{k_2}{c_2}\right).\left(\frac{v}{c_2}\right)^{k_2-1}.\exp\left[-\left(\frac{v}{c_2}\right)^{k_2}\right]\right] \quad (3.16)$$

3.2 Scale and Shape Parameters Estimation Methods

Many researchers studied and compared these probability distribution functions and tried to optimize the accuracy of the assessment of wind potential. It been found in many literatures that, to express the variation with time of the speed of wind, Weibull and Gamma distributions can be considered as the most applied functions amongst the others due to accurate representations of the wind speed distribution they can provide (Justus et al., 1978) (S. A. Akdağ et al., 2010) (Monahan et al., 2011), for those reasons both of them are compared in this work. For calculating the scale and shape parameters, several methods are used. A brief review of the methods is provided in this section.

Graphical estimation method

It is simply functioned by interpolating a straight line to the data using the least squares regression. Data should be arranged in bins before applying the method (Allouhi et al., 2017).

Maximum likelihood method

Which is adopted in this work, because of the high accuracy it can provide in estimating the parameters comparing to the other methods, that is the reason it has been commonly applied in statistics, a wide range of iterations are needed to calculate the coefficients of Weibull distribution (Arslan et al., 2014). The shape and the scale parameters can be expressed by these equations below

$$k = \left[\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right]^{-1} \tag{3.17}$$

$$c = \left[\frac{1}{n}\sum_{i=1}^{n} v_i^k\right]^{-1} \tag{3.18}$$

Moment method

This method expresses the shape the scale factors by iterative solutions of the following equations

$$\bar{v} = \Gamma . c\left(1 + {}^{1}/_{k}\right) \tag{3.19}$$

$$\sigma = c\left[\left(1 + {}^{2}/_{k}\right).\Gamma - \left(1 + {}^{1}/_{k}\right).\Gamma^{2}\right]^{2} \tag{3.20}$$

Where, $\bar{v}$ and σ are the mean speed and the standard deviation, respectively.

The Empirical method of Jestus

Justus et al. (1978) derived a special case from the moment method related to the standard deviation and mean speed. The shape and scale parameters are expressed by

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \qquad 1 \leq k \leq 10 \tag{3.21}$$

$$c = \frac{\bar{v}}{\left(\Gamma + \frac{\Gamma}{k}\right)} \tag{3.22}$$

The Empirical method of Lysen

The formula for calculating the shape parameter is similar to the one in the method of Jestus, while the scale parameter can be calculated by this formula introduced by (Lysen, 1982):

$$c = \bar{v}\left(0.568 + \frac{0.433}{k}\right)^{-\frac{1}{k}} \tag{3.23}$$

Energy pattern factor method

Another method used to determine the parameters of the Weibull distribution, depends on the energy pattern factor, produced by (Seyit A. Akdağ and Dinler, 2009). The energy pattern factor is given by:

$$E_{pf} = \frac{\overline{v^3}}{\bar{v}\hat{}3} \tag{3.24}$$

And k is given by

$$k = 1 + \frac{3.69}{E_{pf}^{2}} \tag{3.25}$$

Where E_{pf} in equation (3.25) is the factor of the pattern of the energy and $\overline{v^3}$ is the mean cube of wind speed.

CHAPTER 4
ECONOMIC ANALYSIS OF WIND TURBINES

4.1 Wind Turbines Classification

The classification of wind turbines, depending on the rating power, rotor diameter and swept area, is categorized in four different size ranges, namely, micro, small, medium and large (International - Natural Resources Canada, n.d., 2004), as shown in Table 4.1.

Table 4.1: Wind turbines Categories (International -Natural Resources Canada, n.d., 2004)

Size	Rated power (kW)	Swept Area (m^2)	Rotor Diameter (m)
Micro	0-1.5	< 7	< 3
Small	1.5-20	7-80	3-10
Medium	20-200	80-500	10-25
Large	200-2000	> 500	> 25

4.2 Selected Turbines Characteristics

Wind turbines with rated power between 0.5 and 2000 kW were used in the analysis. The cut in wind speed beside the rated power are the main parameters for the selection process. Further details about the characteristics of selected turbines can be found in appendix 1.

Table 4.2: Selected turbines characteristics

	Aircon 10	EolSenegal 500	Finn Wind Tuule C 200	P10-20	EWT DW
Hub height [m]	12	18	27	36.6	50
Rated power [kW]	10	0.5	3	20	250
Cut in speed [m/s]	2.5	2	1.9	2.5	2.5
Rated speed [m/s]	11	9	10	10	10
Cut out speed [m/s]	32	12	20	25	25

Table 4.2: Continued

	Enercon E33	P-15-50	DW61-900 kW	Enercon E53	Enercon E82
Hub height [m]	50	50	61	70	130
Rated power [kW]	330	50	900	800	2000
Cut in speed [m/s]	2.5	2.5	2.5	2.5	2.5
Rated speed [m/s]	13	10	11.5	13	12.5
Cut out speed [m/s]	25	25	25	25	25

4.3 Wind Turbines Cost Analysis

Any wind turbines system cost can be expressed as money per kilowatt ($/kW). It varies from one manufacturer to another. Thus, for simplifying the analysis, the cost range for each class is given in the table down (Mathew, 2007).

Table 4.3: Cost ranges of wind turbines (Mathew, 2007)

Power Rate (kW)	Specific cost ($/kW)	Average cost ($/kW)
10–20	2200–2900	2550
20–200	1500–2300	1900
>200	1000–1600	1300

The economic feasibility of any wind energy plant is directly proportional to its capability of generating energy at low operating cost (Kristensen et al., 2000). To determine the cost of generating energy by a wind turbine, the following parameters must be considered (Gökçek and Genç, 2009):

1. Investment cost (including the foundation and grid connection costs etc.).
2. Turbine electricity production over average wind speed.
3. Operation and maintenance costs ($C_{o\&m}$).
4. Discount rate.
5. Plant lifetime.

The factors mentioned are somehow location dependent. However, the most critical parameters are the investment costs and the turbine productivity. The electricity production of wind turbines is extremely dependent on wind conditions, thus, the right choice of the plant site is a critical factor in achieving economic viability (Belabes et al., 2015).

In literature, several methods have been used to compute the cost of wind energy as discussed in (Lackner et al., 2010). The present value cost method (PVC) is adopted in the analysis due to its ability to consider the active development of relevant economic factors and takes into account the different occurrences of costs and incomes.

The PVC method can be expressed as

$$PVC = \left[I + C_{o\&m}\left(\frac{1+i}{r-i}\right) \times \left[1 - \left(\frac{1+i}{1+r}\right)^{n}\right] - S\left(\frac{1+i}{1+r}\right)^{n}\right] \tag{4.1}$$

The discount rate (r), inflation rate (i), machine life (n), investment costs (I) and scrap value (S) are all taking into account in the formula. These variables values are assumed to be as shown in Table 4.3:

Table 4.4: PVC method variables values (Diaf and Notton, 2013)

Parameter	Value	Parameter	Value
r[%]	8	I [%]	68
i[%]	6	S [%]	10
n [year]	20	$C_{o\&m}$[%]	7

Gass et al. (2013) expressed a relation using the PVC value, rated power ($\boldsymbol{P_r}$) and capacity factor ($\boldsymbol{C_f}$) to calculate the unit cost of electricity generation per kW h (UCE) as follow:

$$UCE = \frac{PVC}{t \times P_r \times C_f} \tag{4.2}$$

CHAPTER 5
METHODOLOGY

This chapter presents the methodology pursued in this work, starting with the description of the selected sites. Then, the wind data sources for technical and economic assessment are explained. Moreover, the parameter estimation models, the direction of the wind the variation of its speed with height and the performance analysis of the wind are discussed in this chapter.

5.1 Description of Selected locations

Six locations with different geographical conditions are considered in this study. Table 3.1 describes the coordinates and the characteristics of each location. The map of Northern Cyprus is shown in Figure 5.1 with the six locations marked on it.

Table 5.1: Coordinates and characteristics of selected locations

Station name	Latitude [°N]	Longitude [°E]	Characteristics of the station
Ercan	35° 09' 34	33° 30' 00	Airport
Gazimağusa	35° 06’ 54	33° 56’ 33	coastal
Dipkarpaz	35° 37' 36	34° 24' 31	coastal
Girne	35° 20’ 25	33° 19’ 08	coastal
Güzelyurt	35° 11’ 53	32° 59’ 38	coastal
Lefkoşa	35° 10’ 08	33° 21’ 33	Surrounded by building

Figure 5.1: Studied sites locations

5.2 Wind Data Source

A Sample of 17 years, monthly wins speed data, corresponds to the period of (2000-2016) at Ercan, Gazimağusa, Girne and Güzelyurt, 12 years period (2005-2016) at Dipkarpaz, and 8 years (2009-2016) at Lefkoşa. The variation of the period is due to the lack of the data in that in the two locations in that period. Wind speed recorded by the meteorological office of Northern Cyprus for the chosen locations used for the evaluation of wind potential in this work. The data was captured in hourly basis by a cup anemometer at a height of 10 m and then calculated as a monthly average. The wide range of the collected data aims to increase the accuracy of the evaluation.

5.3 Distribution Functions and Parameters Estimation Model

As previously mentioned in chapter 3, there are various methods which can be used to estimate the potential of wind energy. Weibull and Gamma distribution functions are used and compared. For parameters estimation, Maximum likelihood method is adopted.

5.4 Wind Direction

The assessment of the distribution of the direction of the wind is an essential part of optimizing the position of a wind farm in a site (Fazelpour et al., 2015). The distribution will be present as a wind rose, which is a useful tool of analyzing wind data related to wind directions, expressed by a circular diagram displaying the relative frequency of wind directions in 8 or 16 radial principal direction lines as shown in Figure 5.2. The angle between each line is 22.5° while the length of the lines is depending on the frequency of the wind direction. At the central circle of the wind rose, the frequency of a calm air is given as a number. Wind speed is also expressed in some types of the wind roses (Walker and Shinn, 2002).

5.5 Wind Speed Extrapolation

As mentioned before, the wind speed data used in this work was captured at a height of 10 m. however, to install a wind farm, estimating the speed at a respective turbine hub height is needed. The most commonly used method to extrapolate the wind speed at different hub heights is the power law method expressed by the following equation:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{5.1}$$

Where v_1 and $v_2$denotes to the measured and extrapolated speeds at an initial height h_1 and the extrapolated height h_2, respectively, and α is the power law exponent which is taken for neutral stability as 1/7 (Kamau et al., 2010).

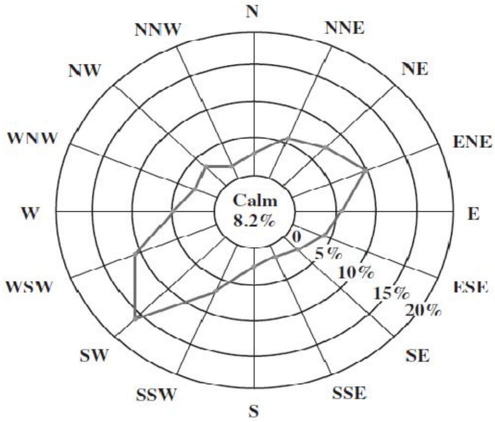

Figure 5.2: Wind rose diagram (Walker and Shinn, 2002)

5.6 Wind Performance Analysis

Turbine power curve ($P_{w(i)}$), (C_f) and the output energy from a wind turbine (E_{out}) are used to analyze the performance of the wind in this study.

5.6.1 Wind Turbines power curve

The power generated ($P_{w(i)}$) by wind turbines can be approximated from the power curve as (Pallabazzer, 2003)

$$P_{w(i)} = \begin{cases} P_r \dfrac{v_i^2 - v_{in}^2}{v_r^2 - v_{in}^2} & (v_i \leq v_i \leq v_r) \\ {}^1\!/_2\, C_p v_r^2 \rho A & (v_r \leq v_i \leq v_o) \\ 0 & (v_i \geq v_o and\ v_i \leq v_i) \end{cases} \tag{5.2}$$

Where,v_{in}, $v_o$are the cut-in and cut-out wind speed respectively,$v_r$is the rated wind speed, C_p is the performance coefficient of the turbine which expressed by (Pallabazzer, 2003)

$$C_p = 2\frac{P_r}{\rho A v_r^3} \tag{5.3}$$

Where ρ is air density, A is rotor swept area of the wind turbine.

5.6.2 Capacity factor (C_f)

One of the essential factors to evaluate the productivity of wind turbines is the capacity factor (Wang et al., 2016). It can be described as, the ratio of the total generated energy over a period of time by a wind turbine to its rated electrical power (P_r) (Ayodele et al., 2014).

$$C_f = \frac{E_{out}}{P_r} \tag{5.4}$$

5.6.3 Total output energy of wind turbines

is the summation of the energy outputs of all potential wind speeds (Gökçek and Genç, 2009)

$$E_{out} = \sum_{i=1}^{n} P_{w(i)} t \tag{5.5}$$

5.7 Climate Change Effects on Wind Speed

The knowledge of the climate change impacts on wind speed is essential to successfully predict the energy generation capacity of a wind turbine in a site. The surrounding surface shape and features can influence the wind properties such as speed and direction from the ground level up to a height of 1000 m, which thereby affect the output energy of a wind turbine (Cradden et al., 2012). In this study, simple analysis of the effects of the climate on the wind characteristics is done.

CHAPTER 6

RESULTS & DISCUSSION

6.1 Wind Speed Characteristics

6.1.1 Monthly mean wind speed

The first step of wind speed data analyzing is to study the behavior of the wind speed with respect to time. The mean monthly wind speed and its variation along the study period are shown in Figures 6.1-6 for all sites.

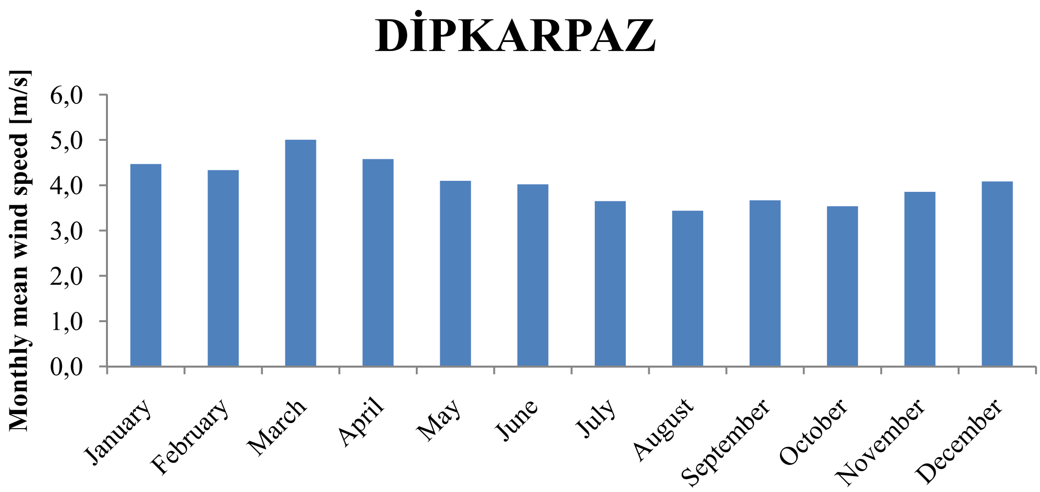

Figure 6.1: Mean monthly wind speed in Dipkarpaz

Starting the analysis with Dipkarpaz, it can be noticed that, the highest mean wind speed with a value of 5 m/s is in March, while the minimum mean value took place in August with a speed equal to 3.4 m/s. The range of speed along the study period is between 2.3 m/s as a minimum speed and 6.2 m/s as a maximum.

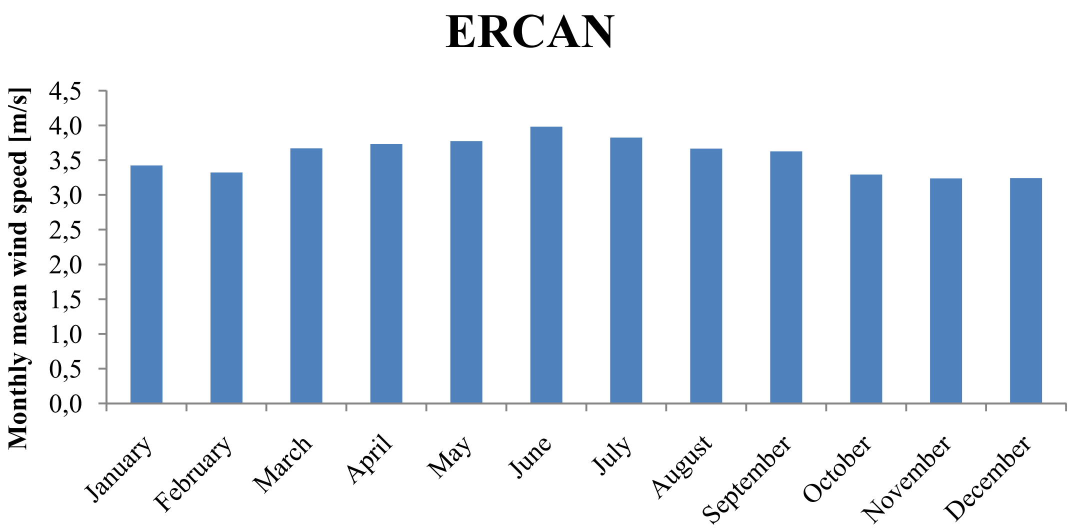

Figure 6.2: Mean monthly wind speed in Ercan

In Ercan case, the highest and lowest values of mean wind speeds are, 4 m/s in June and 3.2 m/s in November and December, respectively. Monthly wind speeds in Ercan during the study period varies between, 1 m/s in February in 2002 as a minimum value and 4.7 m/s in June 2009 as a maximum.

It can be seen from Figure 6.3 that, in Gazimağusa the highest monthly mean wind speed value is 4.1 m/s occurring in January, February and December. On the other hand, May and August are sharing the lowest mean speed value of 3.4 m/s. regarding the variation of the monthly speed values, a wide range of speeds between 2.3 and 7.2 m/s can be noticed.

In Girne, the mean monthly wind speeds, as shown in Figure 6.4, changes between 2.9 m/s as a maximum mean value in January and February and 2.2 m/s as a minimum value in August and October. Looking at the variation part, most speed values are fluctuating between 2 and 4 m/s, but the minimum value is read as 1.1 m/s in October 2002 and the maximum value was recorded as 4.3 m/s in February 2003.

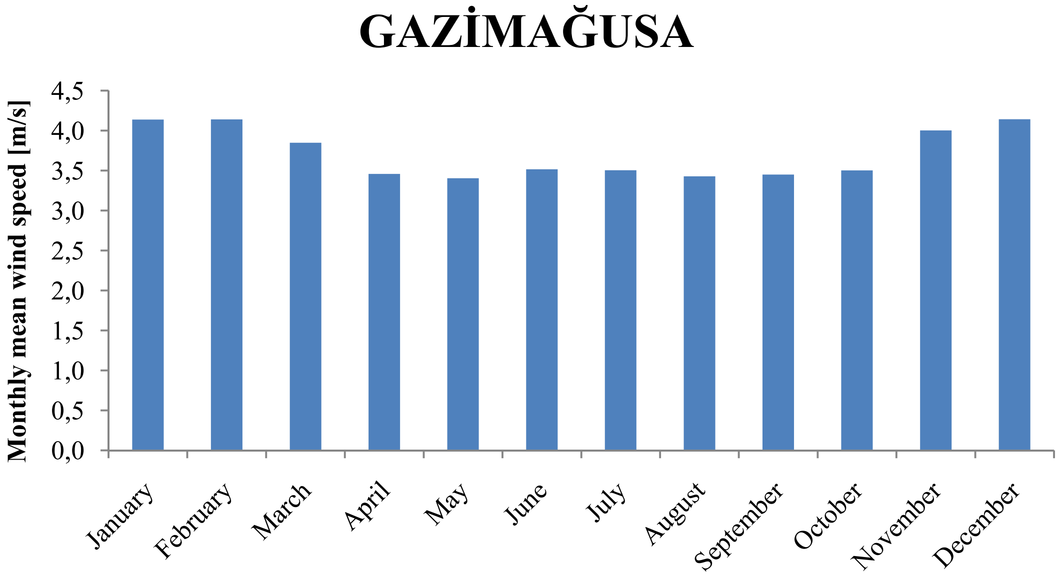

Figure 6.3: Mean monthly wind speed in Gazimağusa

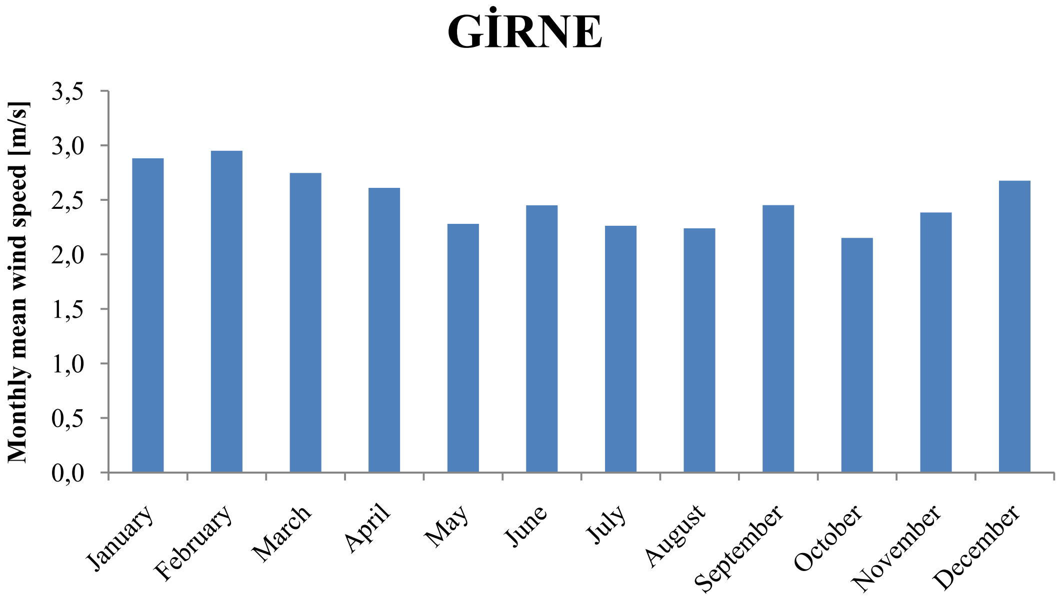

Figure 6.4: Mean monthly wind speed in Girne

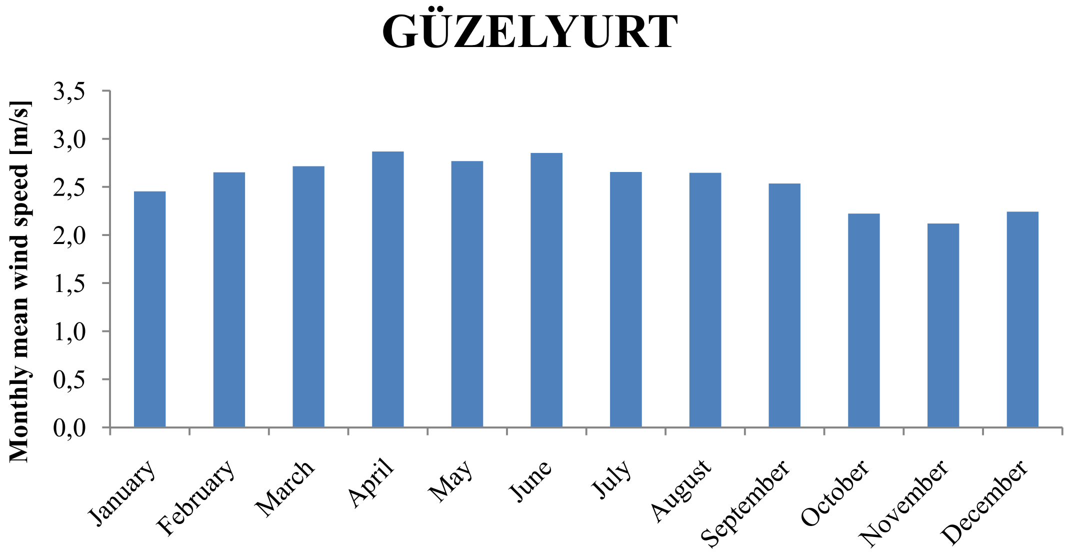

Figure 6.5: Mean monthly wind speed in Güzelyurt

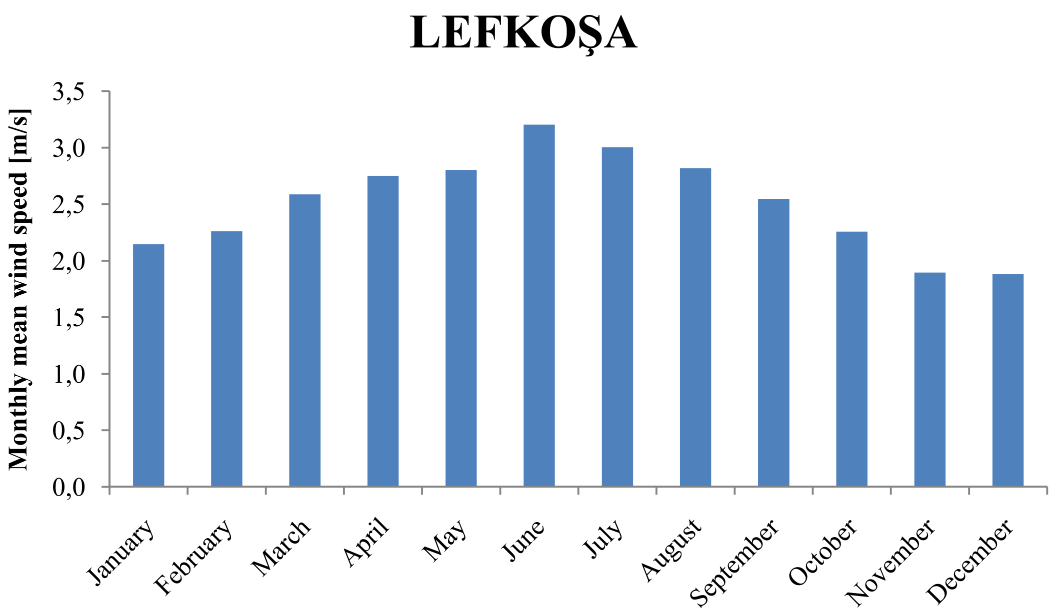

Figure 6.6: Mean monthly wind speed in Lefkoşa

Figure 6.5 shows the monthly wind speed variation in Güzelyurt. The wind speed is the lowest in November with a value equal to 2.1 m/s, while, the highest mean value of speed was calculated as 2.9 m/s which occurred in April and June. The lowest speed captured in Güzelyurt was 1.1 m/s in September 2016. Whereas in April 2001 the highest speed value of 3.6 m/s was recorded.

Between 2009 and 2016 in Lefkoşa, as illustrated in Figure 6.6, the highest mean wind speed can be seen in June with a value of 3.2 m/s, while the lowest value is 1.9 m/s in both November and December. The range of variation in speed values is between 1.5 in November 2010 and 3.5 in June 2009 and 2015 m/s.

6.1.2 Seasonal mean wind speed

Figure 6.7 shows the seasonal variation of mean wind speed in Dipkarpaz. It can be noticed that spring has the highest mean wind speed along the study period followed by winter except 2007 where autumn has mean wind speed higher than winter. The lowest mean wind speed can be seen in summer in 2006, 2007, 2009, 2010, 2014 and 2016. While, in the other years it can be seen in autumn.

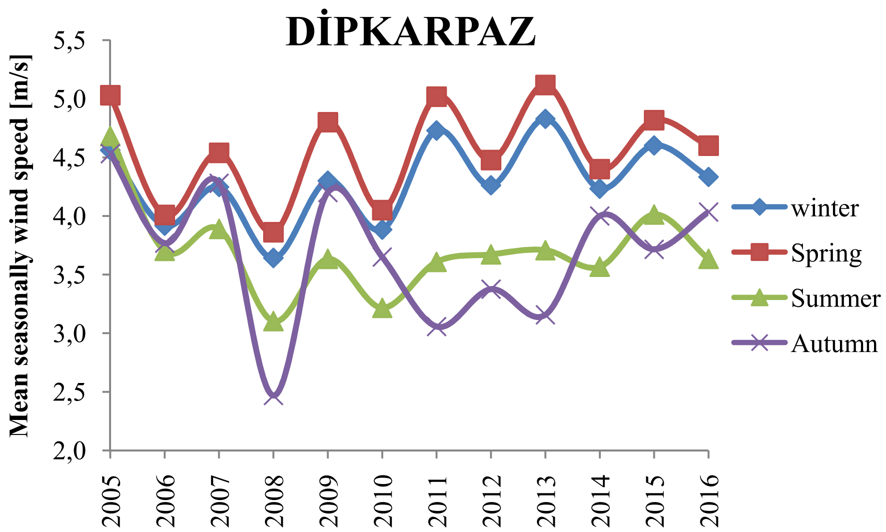

Figure 6.7: Seasonal mean wind speeds in Dipkarpaz

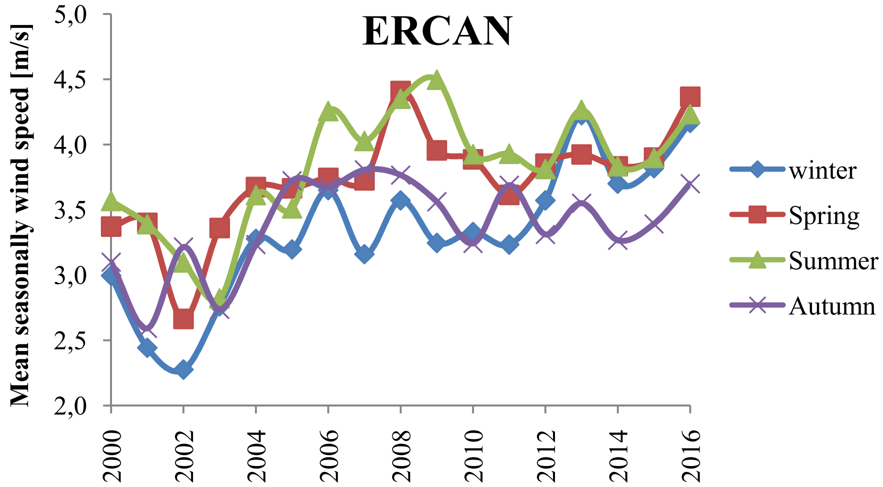

Figure 6.8: Seasonal mean wind speeds in Ercan

In Ercan, the effect of climate change is changing from year to year. The lowest mean speed value is shared between winter and autumn, 8 years each, while the highest mean speed can be seen in summer in 2000, 2001, 2006-2011 and 2013-2015 in autumn in 2002 and in spring in 2003-2005, 2012 and 20016.

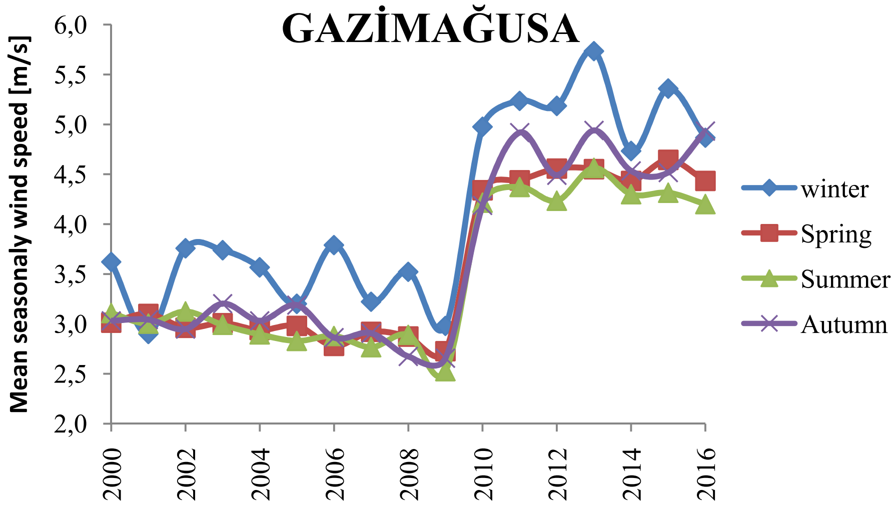

Figure 6.9: Seasonal mean wind speeds in Gazimağusa

Figure 6.9 shows the seasonal mean wind speeds in Gazimağusa. Winter has the highest value in all years excluding 2001 when it has the minimum value among other seasons. The climate effect on wind speed is not noticeable in summer, autumn and spring due to the small mean speed difference between them along the study period.

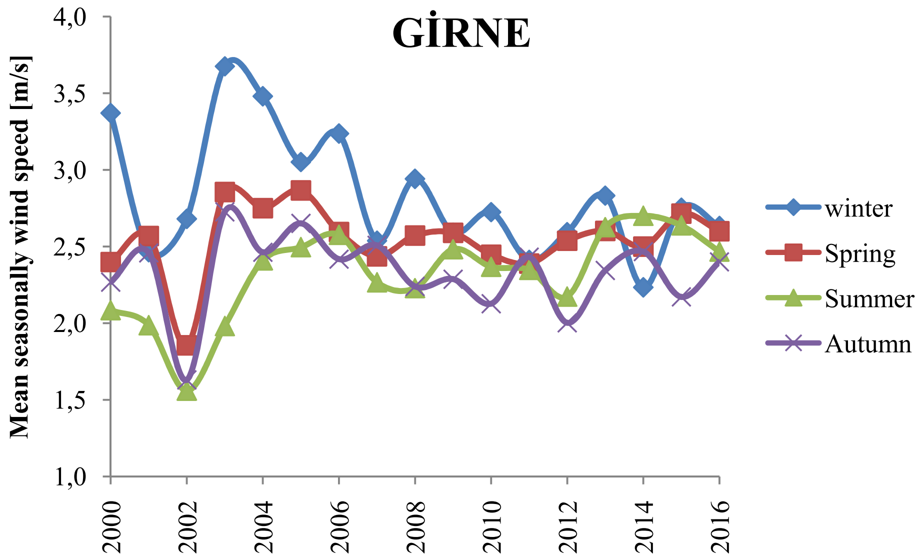

Figure 6.10: Seasonal mean wind speeds in Girne

In Girne, winter has the highest mean wind speed values in all years except for 2001 and 2014 when the highest values can be seen in spring and summer, respectively. In 2011, all seasons have the same mean wind speed value (2.4 m/s), which means that the impact of climate change in that year on wind speed is relatively low.

Figure 6.11 illustrates the mean seasonal wind speed variation in Güzelyurt. Spring has the highest average mean wind speed value of 2.8 m/s. with a small difference, summer come second with a value of 2.7 m/s. autumn and winter have a low average mean wind speed values of 2.3 and 2.4 m/s, respectively.

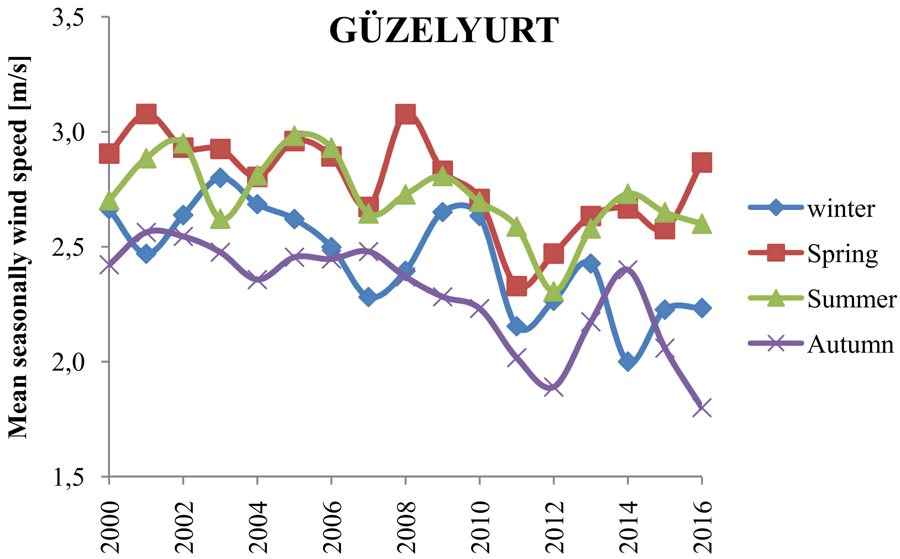

Figure 6.11: Seasonal mean wind speeds in Güzelyurt

In Lefkoşa, the climate change effect is the most. It can be seen that the mean wind speed is increasing from winter to autumn to spring to summer consecutively except for 2010 when the mean speed value in autumn was less than the one in winter.

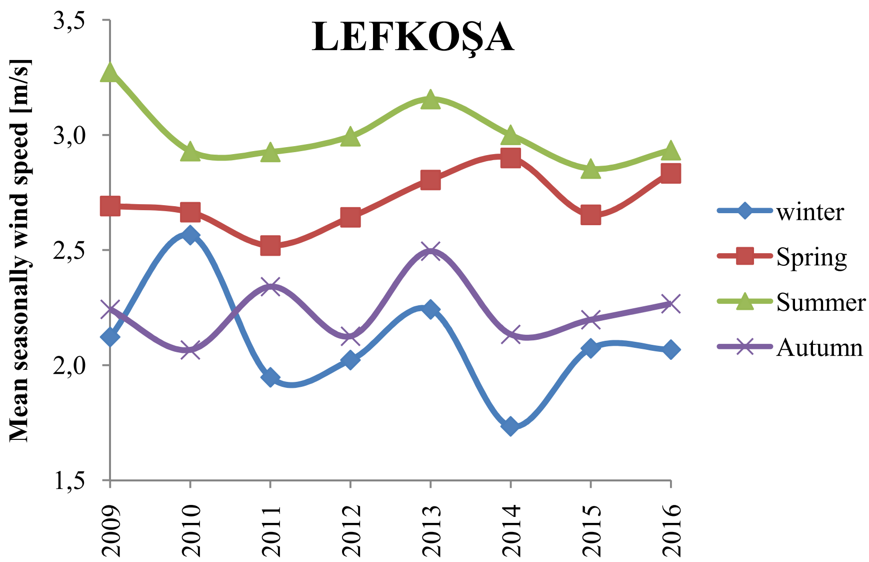

Figure 6.12: Seasonal mean wind speeds in Lefkoşa

6.1.3 Annually mean wind speed

This section expresses the mean values of wind speeds in yearly basis along the study period for all location, which indicates the average speed all over the year. This information can help understanding the difference in wind speed between the studied locations in a plain way.

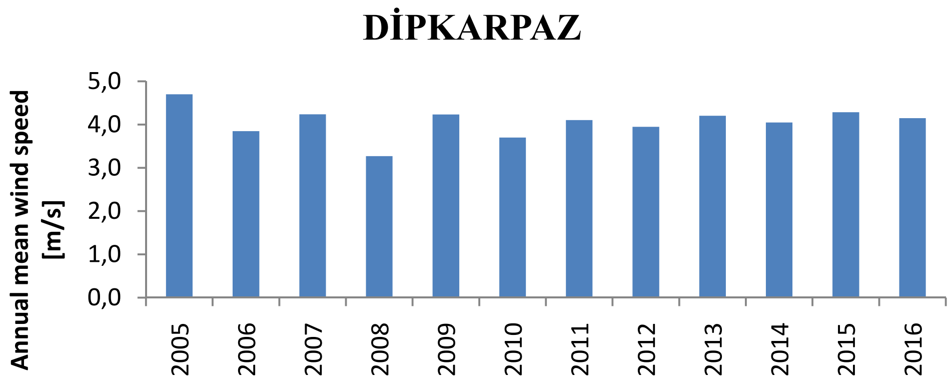

Figure 6.13: Mean annual wind speed in Dipkarpaz

First, Figure 6.13 shows the mean annual wind speed in Dipkarpaz, the values vary between 3.3 m/s as a minimum value, which can be seen in 2008, and 4.7 m/s as a maximum in 2005. In the rest, the values are fluctuating between 3.9 and 4.2 m/s. The average value of all years is 4.1 m/s.

In Ercan, as shown in Figure 6.14, in earlier years the mean values of speed were low and they kept decreasing until 2002, after that a raise in values started until 2006, then the values fluctuated until 2016 which have the highest value of 4.1 m/s. The average overall value of the mean annual wind speed in Ercan is 3.6 m/s.

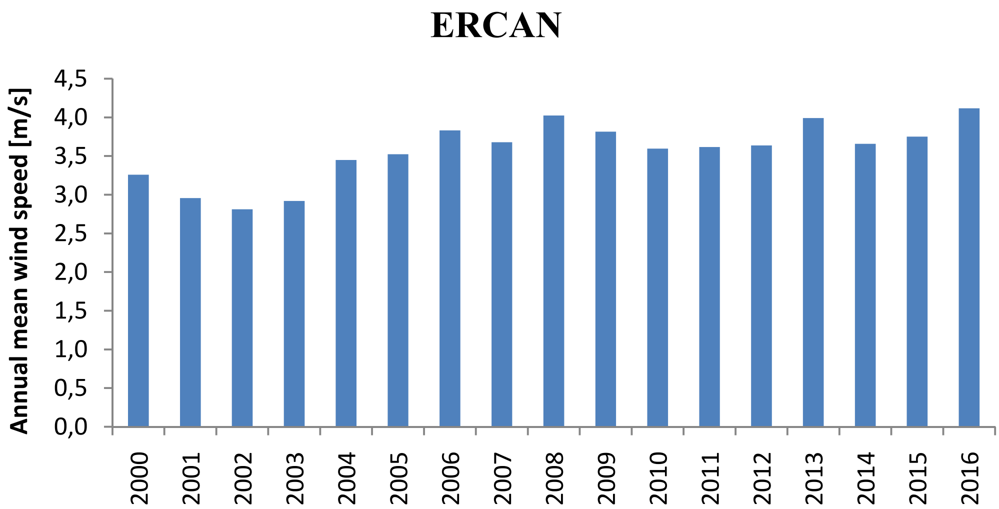

Figure 6.14: Mean annual wind speed in Ercan

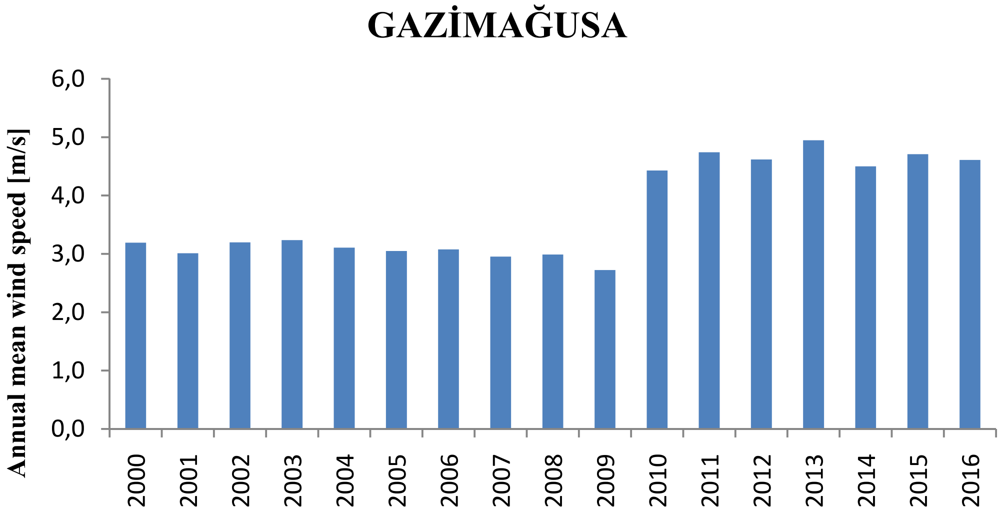

Figure 6.15: Mean annual wind speed in Gazimağusa

Gazimağusa, on the other hand, showed a nearly steady behavior of mean speed between the years 2000 and 2008 with the values changing between 3 and 3.2 m/s as shown in Figure 6.15, a drop took a place in 2009 when the lowest mean value can be seen as 2.7 m/s, after that tremendously increase in values started from 2010, reaching the highest value in 2013 equal to 4.9 m/s.

The Figure shows two phases of wind speed value changing from an average of 3.1 m/s in one period to values of 4.7 m/s average value in the other, while the total mean wind speed average of all years is 3.7 m/s.

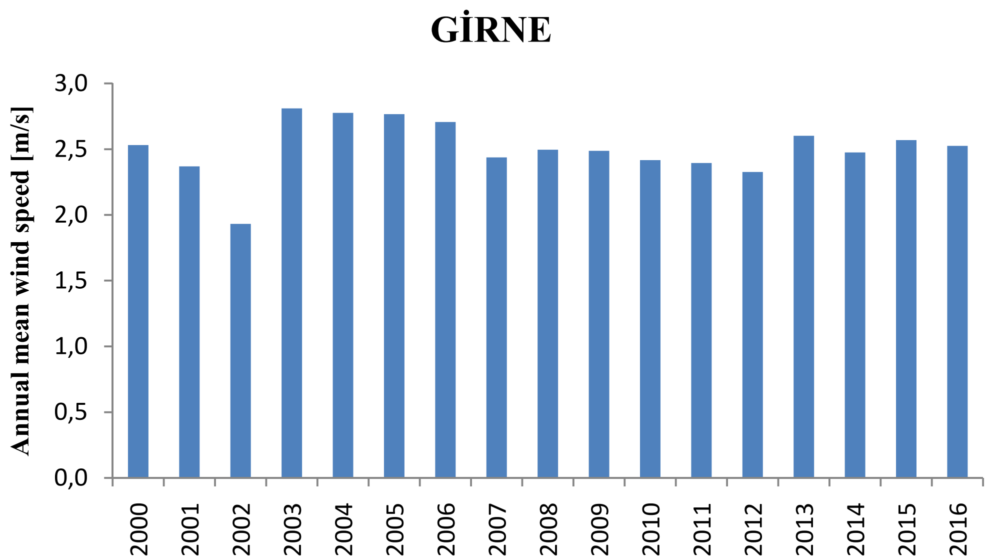

Figure 6.16: Mean annual wind speed in Girne

In Girne, all along the study period, all annual mean wind speed values are varying between 2.4 and 2.8 m/s except for 2002, when the mean wind speed value was 1.9 m/s which is the minimum value. The maximum value is 2.8 m/s in three years in raw (2003-2005). The overall mean value of annual wind speeds in Girne is 2.5 m/s.

Moving to Güzelyurt, Figure 6.17 shows that, the overall annual mean wind speed is 2.6 m/s. The values in most of the years are slightly changing above and under the overall mean value by 1 or 2 degrees. The minimum value is 2.2 m/s calculated in 2012 and the maximum value was calculated to be 2.8 m/s in both 2002 and 2005. It can be noticed that, in the case of Girne, the range of value variation is small, 0.6 m/s is the difference between the highest and lowest value.

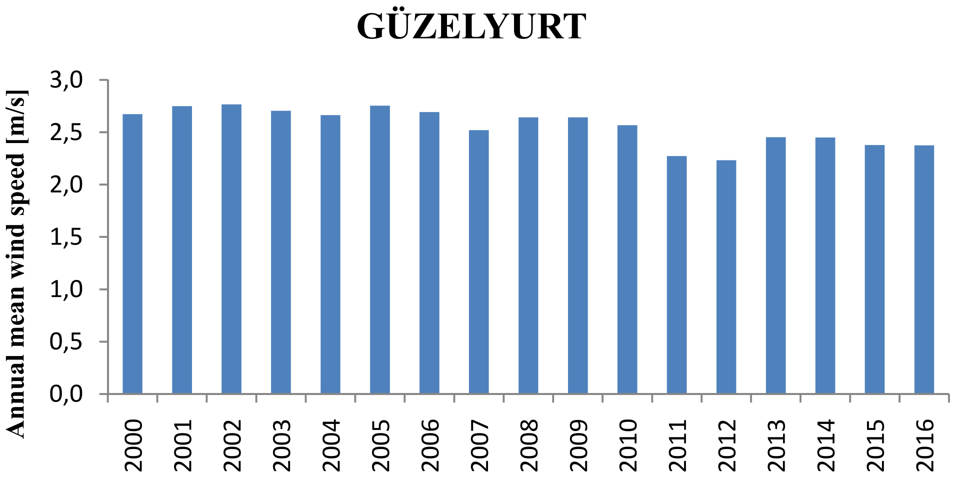

Figure 6.17: Mean annual wind speed in Güzelyurt

Finishing with Lefkoşa, as shown in Figure 6.18, the minimum mean value was calculated to be 2.4 m/s in 2011, 2012, 2014 and 2015. While the maximum values were 2.7 m/s in 2013. The overall mean wind speed value is 2.5 m/s. It can be noticed that the least difference between the maximum and the minimum mean values can be seen in Lefkoşa (0.3 m/s).

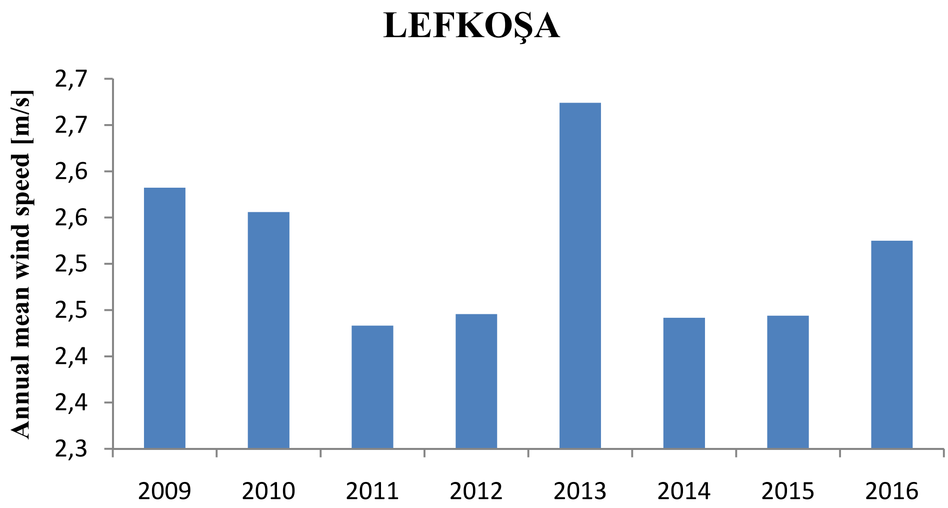

Figure 6.18: Mean annual wind speed in Lefkoşa

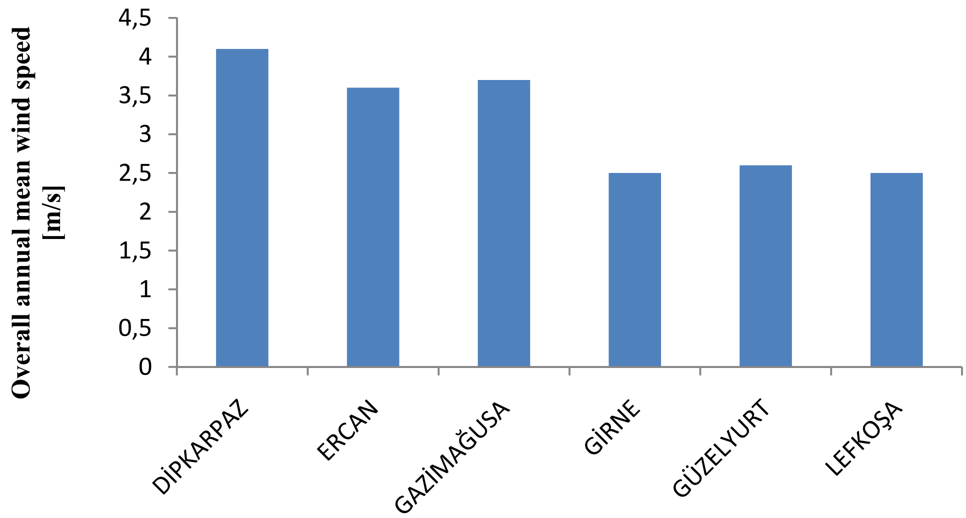

Figure 6.19: Overall mean annual wind speed in all locations

By analyzing the data, we can see that, among all locations, Dipkarpaz has the highest overall annual mean wind speed with a value of 4.1 m/s, followed by Gazimağusa with the value equal to 3.7 m/s, Ercan comes third with 3.6 m/s, then, Güzelyurt with 2.6 m/s mean overall annual speed, Girne and Lefkoşa are sharing the last place with 2.5 m/s as illustrated in Figure 6.19.

6.2 Wind Direction

Average monthly wind direction for each month along the study period for all locations is illustrated by the wind frequency rose as shown in Figure 6.20. Increasing wind frequency was used as an indicator of the main direction. The dominant direction of the wind for Gazimağusa (Famagusta) was found to be Northeast (NE) in autumn, the highest wind frequencies distribution can be seen in November. While the second direction from which the wind blows mostly was determined as the west (W) during autumn. In the winter season, the dominant direction of the wind was found to be southwest (SW) with a frequency value of almost 30%.

Additionally, it can be seen that during winter, wind direction with the greatest frequency is east (E) and southwest (SW) for Güzelyurt (Morphou) and Ercan, respectively. In the spring season, wind direction with the greatest frequency in March and April is east and west in May for Güzelyurt. Also, for Ercan, wind direction with the greatest frequency is Southwest in March and west in April and May. In summer and autumn season, wind direction with the greatest frequency is west for Ercan. For Güzelyurt, wind direction with the greatest frequency is Northwest (NW) during summer. The wind direction with the greatest frequency is NW during September and E during October and November for Morphou.

Most of the wind blows from the East, Northeast and South direction at Girne (Kyrenia) which depends on the season. Moreover, the data from the present location of Lefkoşa (Nicosia) indicates that southwest has the greatest frequency in all seasons.

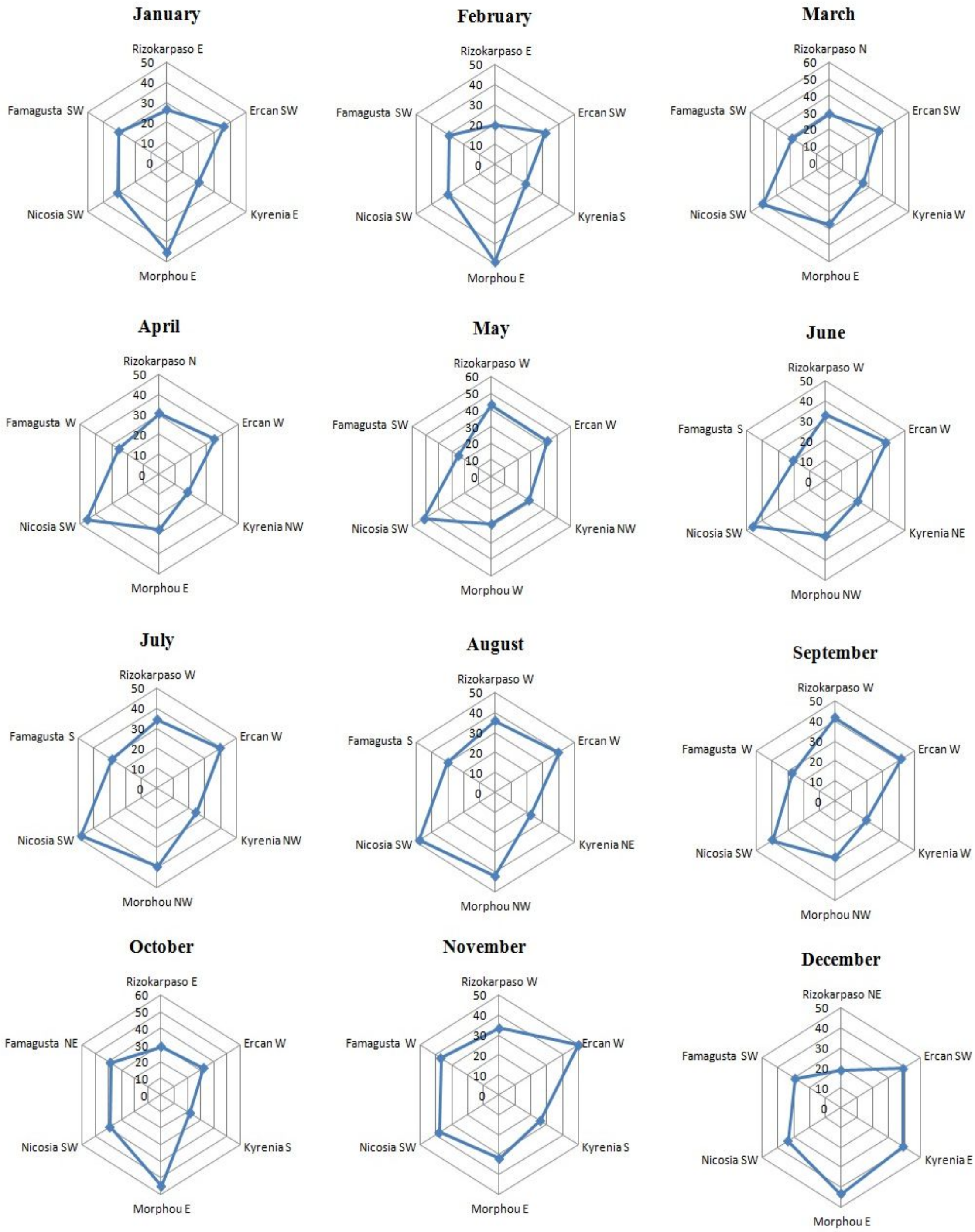

Figure 6.20: Monthly wind frequency rose for all locations

6.3 Weibull and Gamma Functions Comparison

The most used functions for wind energy potential estimation are Weibull and Gamma functions. In this section, both functions are applied and compared. A graphical presentation of Probability Density and Cumulative Distribution Functions for both Weibull and Gamma distribution functions produced by Matlab software was conducted for all locations in an annual basis. The mean annual charts for all locations are presented in Figures 6.20-31. After that, the r-squared function (RSQ) is applied to test the fit quality by comparing the average RSQ value for all locations of both Weibull and Gamma distribution functions as illustrated in Table 6.1. It must be noted that the y-axis title 'Density' in the charts referrers to Probability Density Function, also the yearly PDF and CDF charts are provided in Appendix 1.

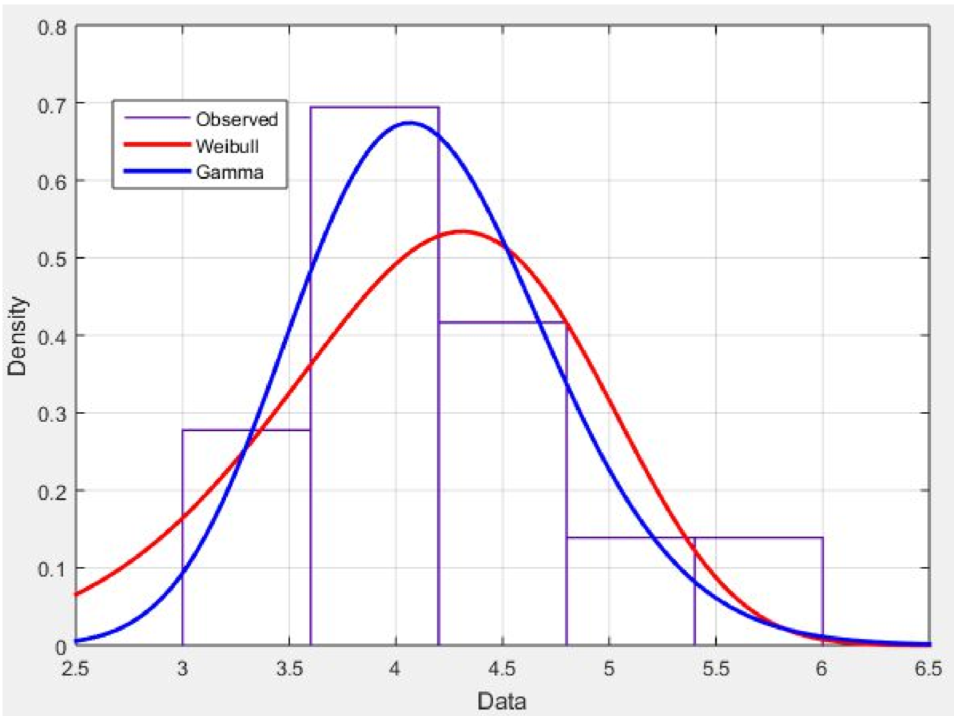

Figure 6.21: Weibull and Gamma functions PDF Chart of Dipkarpaz

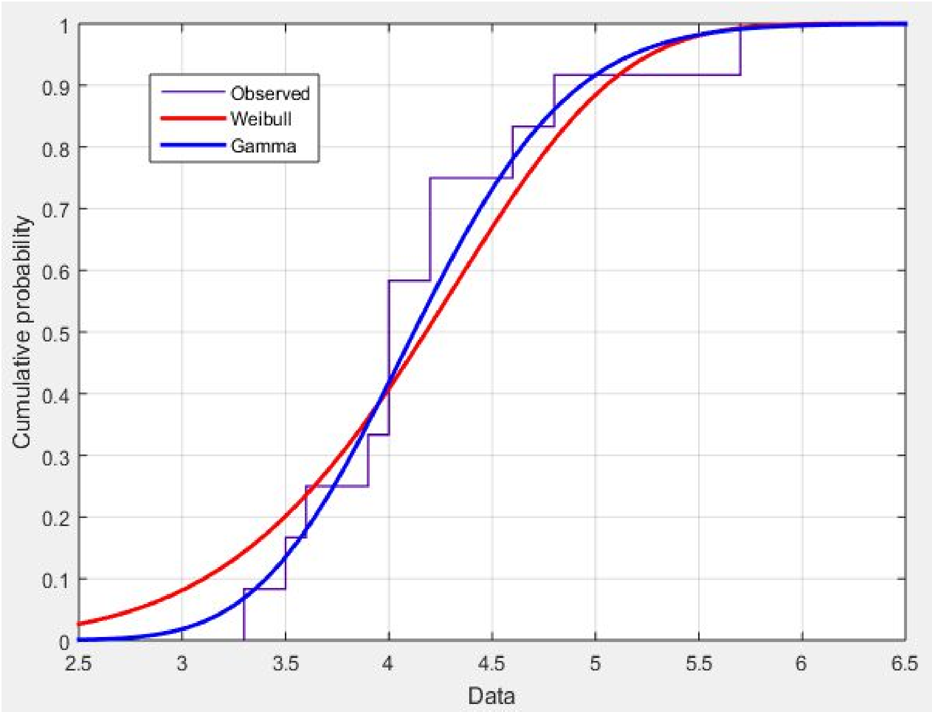

Figure 6.22: Weibull and Gamma functions CDF Chart of Dipkarpaz

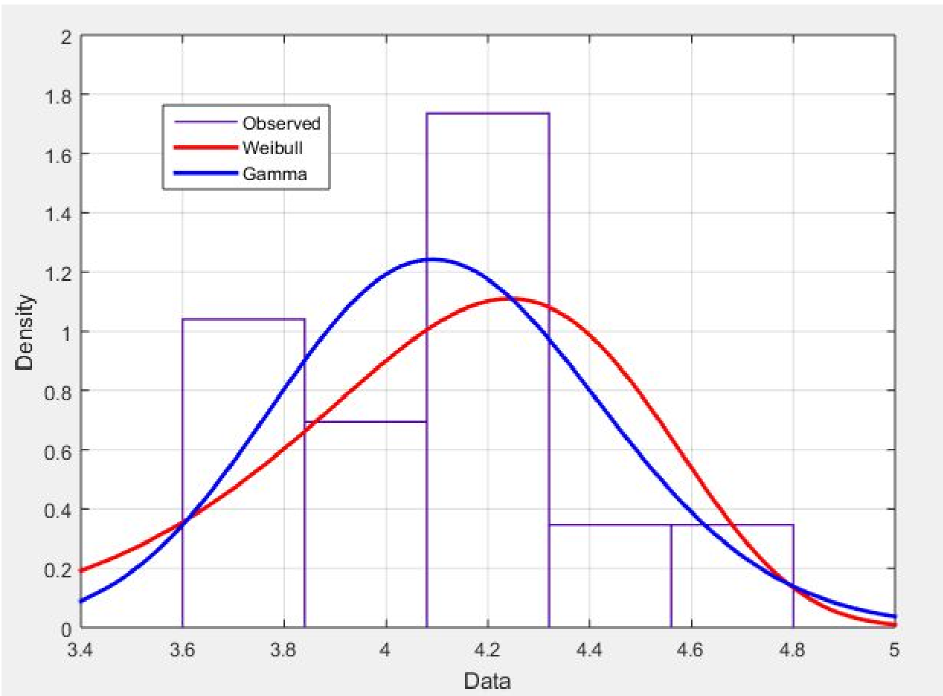

Figure 6.23: Weibull and Gamma functions PDF Chart of Ercan

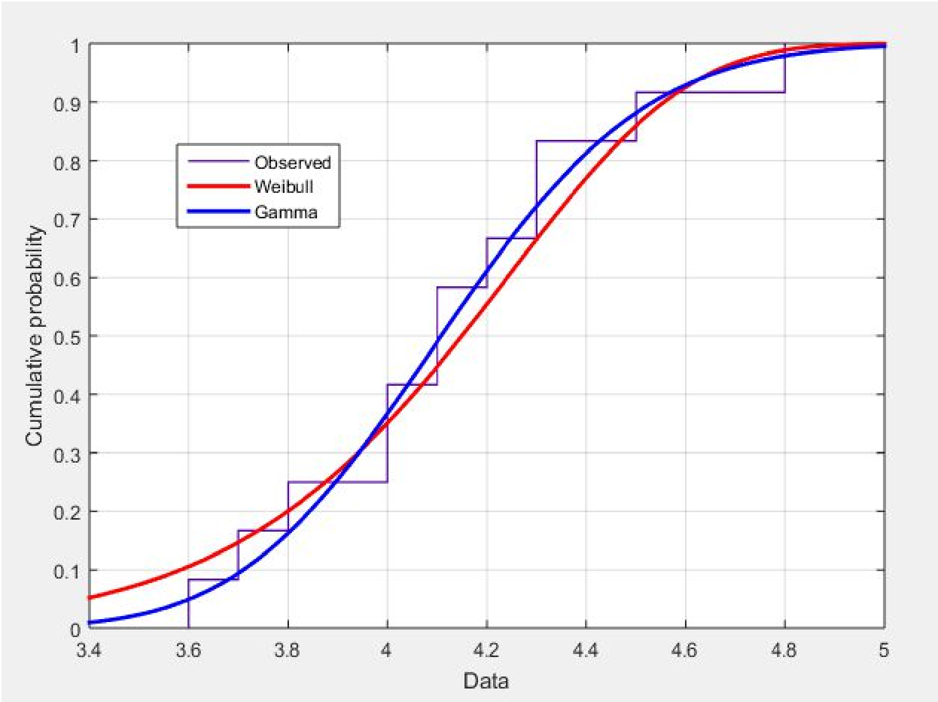

Figure 6.24: Weibull and Gamma functions CDF Chart of Ercan

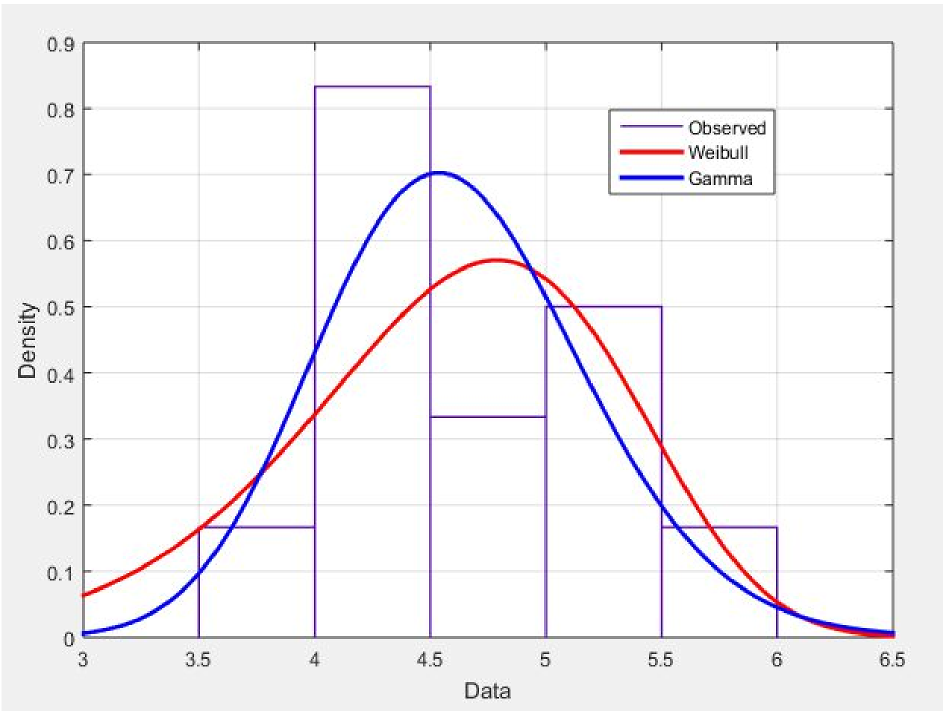

Figure 6.25: Weibull and Gamma functions PDF Chart of Gazimağusa

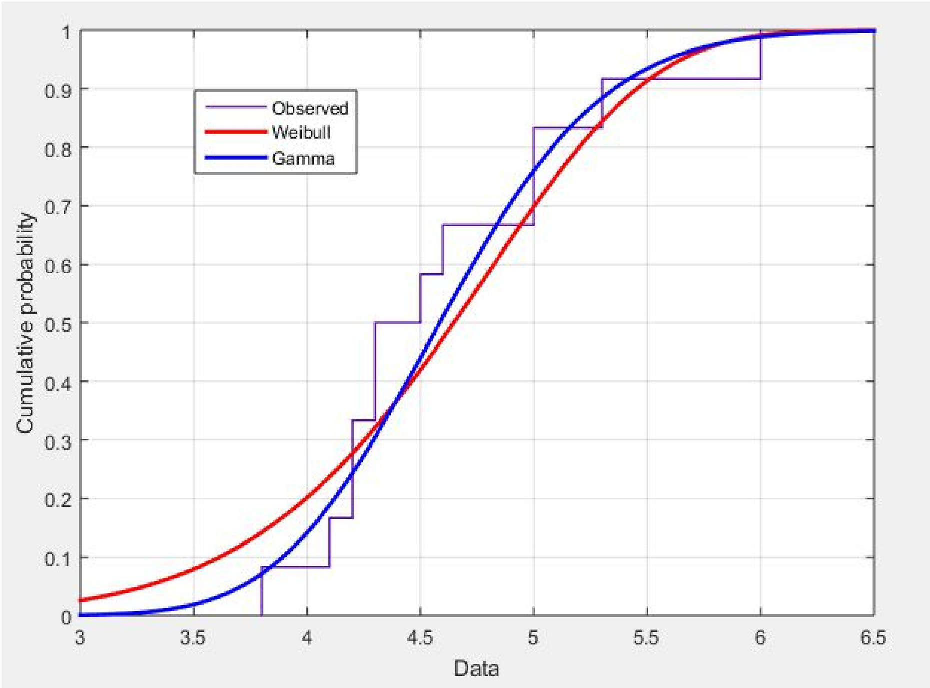

Figure 6.26: Weibull and Gamma functions CDF Chart of Gazimağusa

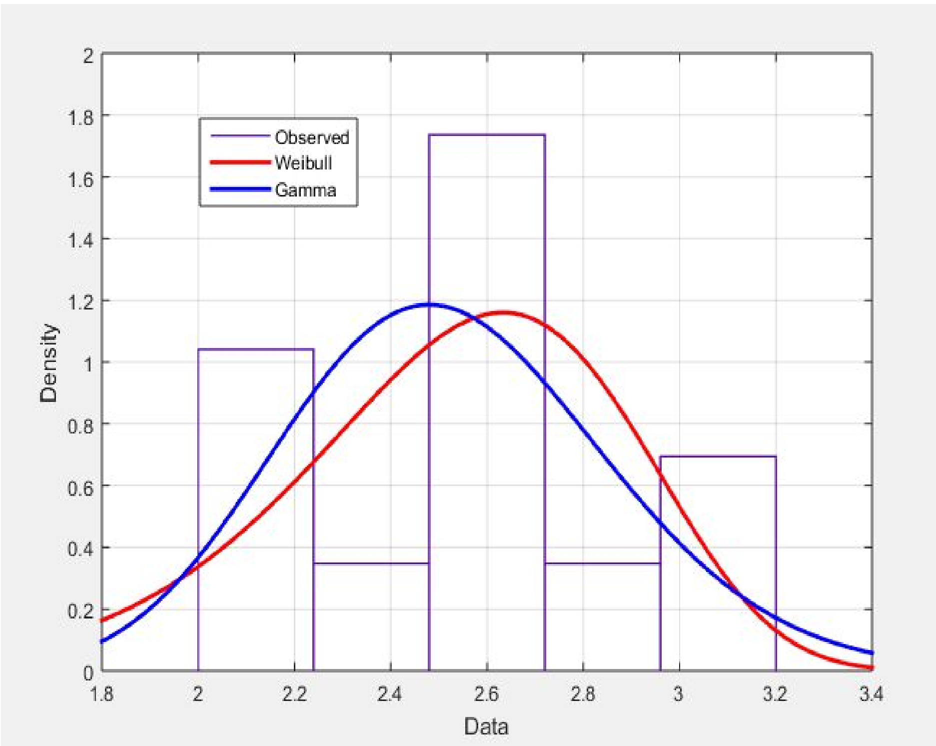

Figure 6.27: Weibull and Gamma functions PDF Chart of Girne

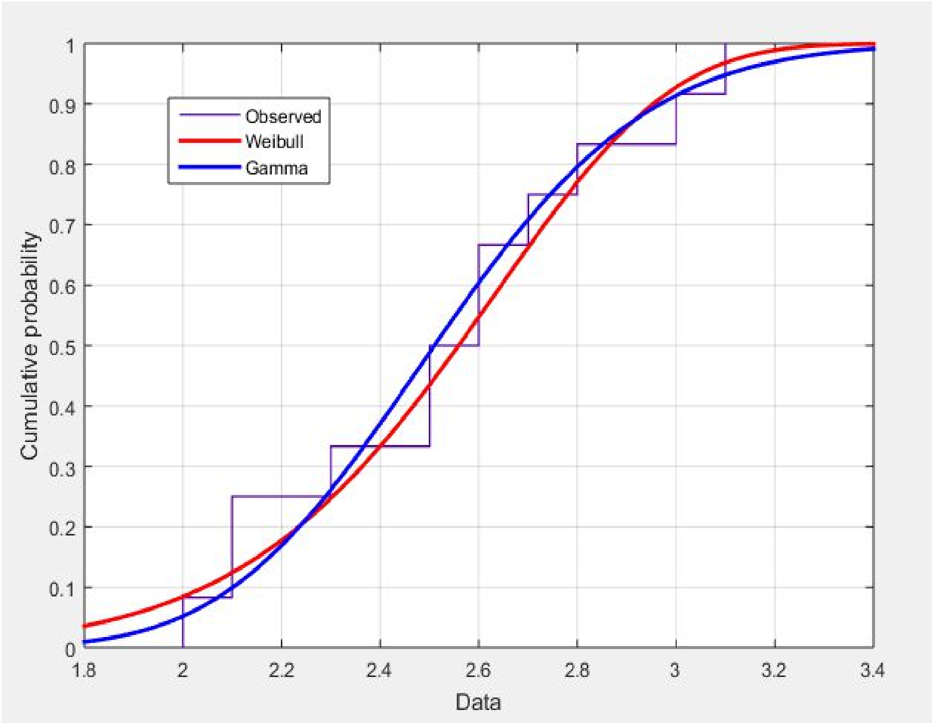

Figure 6.28: Weibull and Gamma functions CDF Chart of Girne

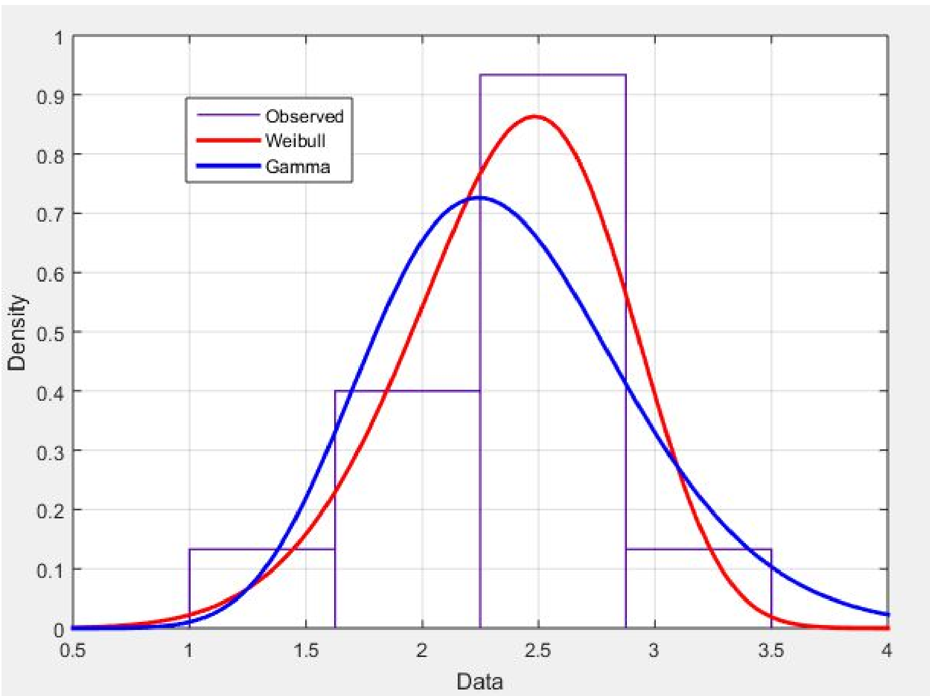

Figure 6.29: Weibull and Gamma functions PDF Chart of Güzelyurt

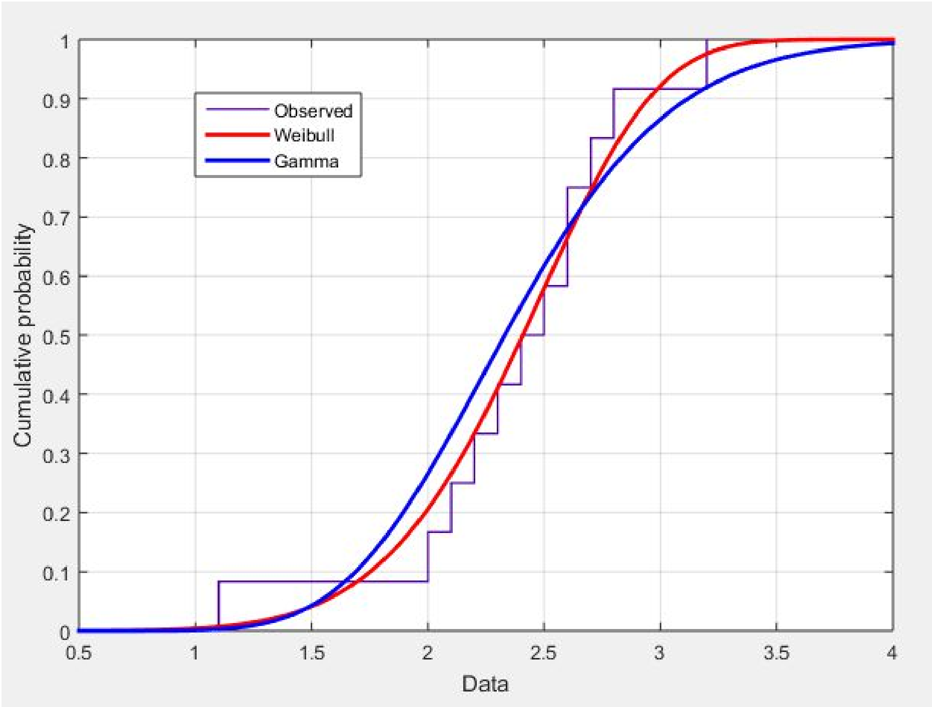

Figure 6.30: Weibull and Gamma functions CDF Chart of Güzelyurt

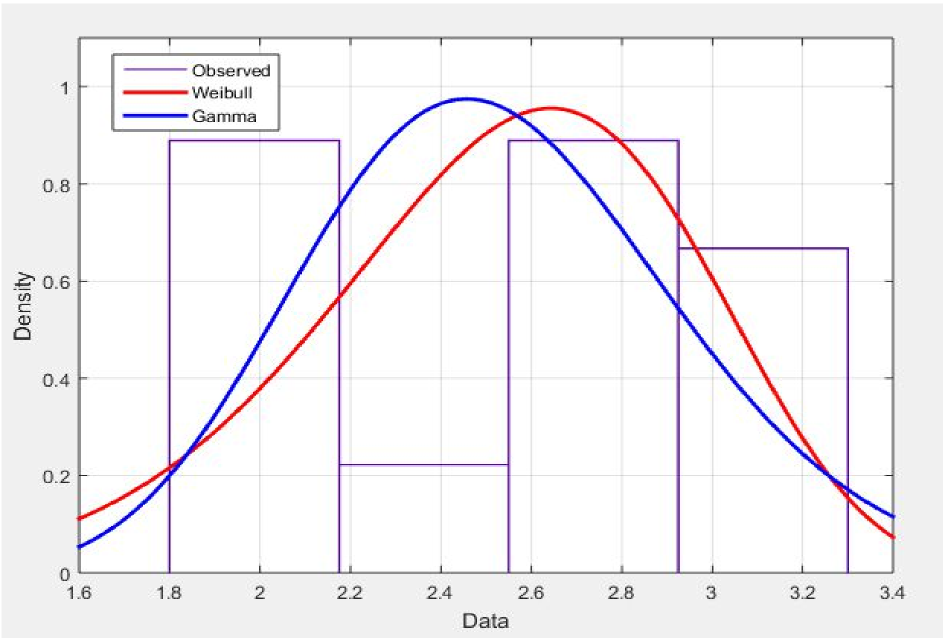

Figure 6.31: Weibull and Gamma functions PDF Chart of Lefkoşa

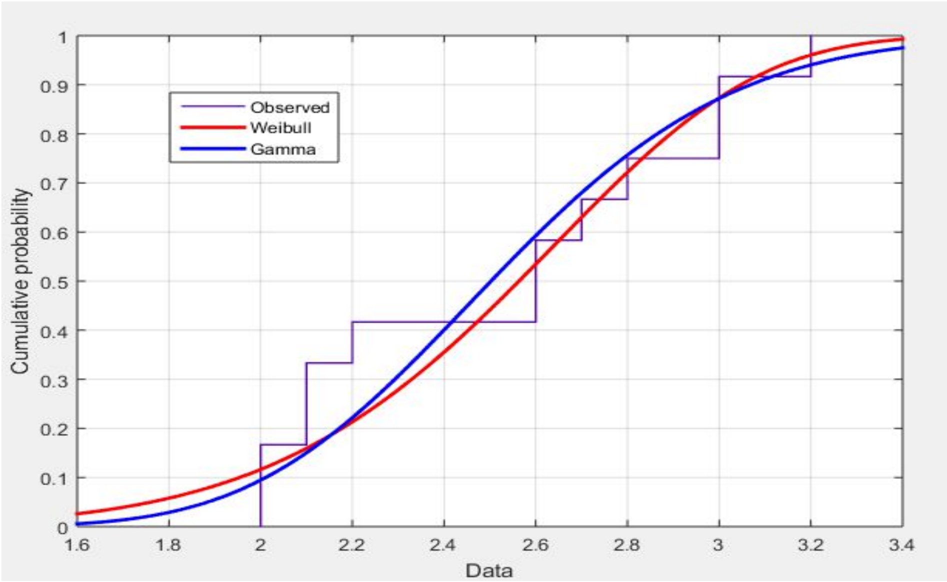

Figure 6.32: Weibull and Gamma functions CDF Chart of Lefkoşa

As illustrated in Figures 6.20-31, both Weibull and Gamma functions are in good agreement with observed data.

Table 6.1: RSQ values for Weibull and Gamma functions

	RSQ						
	Dipkarpaz	Ercan	Gazimağusa	Girne	Güzelyurt	Lefkoşa	**Average**
Weibull	0.947	0.996	0.998	0.936	0.989	0.894	**0.960**
Gamma	0.951	0.991	0.999	0.947	0.979	0.866	**0.955**

RSQ value indicates the quality of data agreement. If RSQ value equal 1, then the error between the fitted data and the original ones is 0, thus, the closest the RSQ value to 1 the better. As it can be seen in the table above the average RSQ value for Weibull distribution function is higher than average RSQ value of Gamma function, therefore, the Weibull distribution function is adopted in this study.

6.4 Weibull Function Parameters and Wind Power Density

Tables 6.2-7 show the scale and shape parameter for the Weibull function, actual and distributed mean wind speed and observed and distributed wind power density for all location during the study period using Maximum likelihood method.

Table 6.2: Weibull function parameters for Dipkarpaz

Parameters	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
k	6,6	8,5	11,1	5,1	10,1	9,2
c (m/s)	5,0	4,1	4,4	3,6	4,4	4,0
Mean speed (m/s)	4,7	3,9	4,2	3,3	4,2	3,7
power density (kW/m^2)	69,5	37,1	48,2	24,6	48,4	33,9
actual mean speed (m/s)	4,7	3,8	4,2	3,3	4,2	3,7
observed power density	63,6	34,9	46,6	21,4	46,5	31,0
Parameters	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
k	4,4	5,9	4,5	10,0	6,2	6,3
c (m/s)	4,5	4,3	4,6	4,3	4,6	4,4
Mean speed (m/s)	4,1	3,9	4,2	4,0	4,3	4,1
power density (kW/m^2)	51,6	41,7	55,0	42,4	53,5	47,1
actual mean speed (m/s)	4,1	3,9	4,2	4,1	4,3	4,2
observed power density	42,3	37,7	45,5	40,7	48,3	43,8

The relationship between Weibull parameters and energy production can be analyzed by equation (3.3). WPD increases when c value increased and k value decreased. In the case of Dipkarpaz, the highest value of the scale parameter is 5, which came along with the highest WPD, at 2005. The lowest k value took a place in 2011 with a value equals 4.4.

Table 6.3: Weibull function parameters for Ercan

Parameters	2000	2001	2002	2003	2004	2005
k	9,7	6,0	5,0	6,6	12,4	14,6
c (m/s)	3,4	3,2	3,1	3,2	3,6	3,6
Mean speed (m/s)	3,2	2,9	2,8	2,9	3,4	3,5
power density (kW/m^2)	21,9	17,4	15,7	17,0	25,5	27,3
actual mean speed (m/s)	3,3	3,0	2,8	2,9	3,4	3,5
observed power density	21,2	15,8	13,6	15,2	25,1	26,8
Parameters	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
k	10,5	12,6	10,9	8,3	10,3	14,4
c (m/s)	4,0	3,8	4,2	4,0	3,8	3,8
Mean speed (m/s)	3,8	3,7	4,0	3,8	3,6	3,6
power density (kW/m^2)	35,5	31,7	41,5	36,0	29,8	29,8
actual mean speed (m/s)	3,8	3,7	4,0	3,8	3,6	3,6
observed power density	34,5	30,5	39,9	34,0	28,5	29,0
Parameters	**2012**	**2013**	**2014**	**2015**	**2016**	
k	12,5	13,8	9,6	17,3	12,8	
c (m/s)	3,8	4,1	3,8	3,9	4,3	
Mean speed (m/s)	3,6	4,0	3,7	3,8	4,1	
power density (kW/m^2)	30,1	40,0	31,3	32,9	43,4	
actual mean speed (m/s)	3,6	4,0	3,7	3,8	4,1	
observed power density	29,5	38,9	30,0	32,3	42,7	

In Ercan, c values are varying between 3.1 and 4.3 in 2002 and 2016, respectively. Thus the highest power density value is read at 2016. The effect of k parameter value on the WPD is observable in the case of 2001 and 2003 when the c value in both years is the same (3.2) the WPD of 2001 is higher because of the decrease in k value compared with 2003.

Moving to Gazimağusa, the values of k are changing between 5.2 and 14.6 in 2008 and 2014, respectively. C parameter maximum value is reached in 2013 as 5.3 with WPD equals 74.2, while, the minimum value is 2.8 in 2009.

Table 6.4: Weibull function parameters for Gazimağusa

Parameters	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
k	11,7	13,3	7,3	6,6	7,3	13,5
c (m/s)	3,3	3,1	3,4	3,4	3,3	3,2
Mean speed (m/s)	3,2	3,0	3,2	3,2	3,1	3,0
power density (kW/m^2)	20,5	17,3	21,1	21,9	19,7	17,6
actual mean speed (m/s)	3,2	3,0	3,2	3,2	3,1	3,0
observed power density	19,9	16,7	20,0	20,7	18,4	17,4
Parameters	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
k	6,2	13,3	5,2	11,5	9,3	9,1
c (m/s)	3,3	3,1	3,2	2,8	4,6	5,0
Mean speed (m/s)	3,0	2,9	3,0	2,7	4,4	4,7
power density (kW/m^2)	18,9	16,0	18,6	12,4	54,8	68,2
actual mean speed (m/s)	3,1	3,0	3,0	2,7	4,4	4,7
observed power density	17,9	15,8	16,4	12,4	53,2	65,3
Parameters	**2012**	**2013**	**2014**	**2015**	**2016**	
k	5,9	5,5	14,6	8,8	7,5	
c (m/s)	4,9	5,3	4,7	5,0	4,9	
Mean speed (m/s)	4,6	4,9	4,5	4,7	4,6	
power density (kW/m^2)	65,6	81,5	56,8	67,7	63,2	
actual mean speed (m/s)	4,6	4,9	4,5	4,7	4,6	
observed power density	60,3	74,2	55,8	63,9	59,9	

Scale parameter values are fluctuating between 2.1 and 3 in Girne as shown in Table 6.5. The shape parameter values on the other hand, have a minimum of 3.3 in 2002 and a maximum of 12.9 in 2007.

Table 6.5: Weibull function parameters for Girne

Parameters	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
k	4,6	5,3	3,3	3,7	5,5	6,6
c (m/s)	2,8	2,6	2,1	3,1	3,0	3,0
Mean speed (m/s)	2,5	2,4	1,9	2,8	2,8	2,8
power density (kW/m^2)	11,7	9,3	5,8	16,9	14,8	14,0
actual mean speed (m/s)	2,5	2,4	1,9	2,8	2,8	2,8
observed power density	9,9	8,1	4,4	13,6	13,1	13,0

Table 6.5: Continued

Parameters	2006	2007	2008	2009	2010	2011
k	6,8	12,9	5,9	9,6	6,1	9,9
c (m/s)	2,9	2,5	2,7	2,6	2,6	2,5
Mean speed (m/s)	2,7	2,4	2,5	2,5	2,4	2,4
power density (kW/m^2)	13,1	9,0	10,6	9,9	9,6	8,7
actual mean speed (m/s)	2,7	2,4	2,5	2,5	2,4	2,4
observed power density	12,1	8,9	9,5	9,4	8,6	8,4
Parameters	**2012**	**2013**	**2014**	**2015**	**2016**	
k	6,1	6,9	6,3	8,6	8,4	
c (m/s)	2,5	2,8	2,7	2,7	2,7	
Mean speed (m/s)	2,3	2,6	2,5	2,6	2,5	
power density (kW/m^2)	8,5	11,8	10,1	10,9	10,4	
actual mean speed (m/s)	2,3	2,6	2,5	2,6	2,5	
observed power density	7,7	10,8	9,3	10,4	9,9	

Table 6.6: Weibull function parameters for Güzelyurt

Parameters	2000	2001	2002	2003	2004	2005
k	10,9	7,2	10,9	9,3	10,4	11,9
c (m/s)	2,8	2,9	2,9	2,9	2,8	2,9
Mean speed (m/s)	2,7	2,7	2,8	2,7	2,7	2,8
power density (kW/m^2)	11,9	13,7	13,5	12,7	12,0	13,4
actual mean speed (m/s)	2,7	2,7	2,8	2,7	2,7	2,8
observed power density	11,7	12,7	13,0	12,1	11,6	12,8
Parameters	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
k	11,0	15,1	8,7	12,4	7,6	8,3
c (m/s)	2,8	2,6	2,8	2,8	2,7	2,4
Mean speed (m/s)	2,7	2,5	2,6	2,6	2,6	2,3
power density (kW/m^2)	12,4	10,0	11,9	11,6	11,1	7,6
actual mean speed (m/s)	2,7	2,5	2,6	2,6	2,6	2,3
observed power density	12,0	9,8	11,3	11,3	10,4	7,2
Parameters	**2012**	**2013**	**2014**	**2015**	**2016**	
k	8,1	9,4	7,9	8,2	5,9	
c (m/s)	2,4	2,6	2,6	2,5	2,6	
Mean speed (m/s)	2,2	2,5	2,5	2,4	2,4	
power density (kW/m^2)	7,2	9,5	9,7	8,8	9,1	
actual mean speed (m/s)	2,2	2,5	2,4	2,4	2,4	
observed power density	6,8	9,0	9,0	8,2	8,2	

In Güzelyurt, as shown in Table 6.6,a small range of value changing is observable in Table 6.6 for both c and k (2.4 - 2.9) and (5.9 – 15.1), respectively, compared with the other locations, which indicates a steady wind speed variation behavior in the location with respect to time.

Table 6.7: Weibull function parameters for Lefkoşa

Parameters	2009	2010	2011	2012	2013	2014	2015	2016
k	5,5	6,7	6,9	6,1	7,4	4,5	8,6	6,9
c (m/s)	2,8	2,8	2,6	2,6	2,9	2,7	2,6	2,7
Mean speed (m/s)	2,6	2,6	2,4	2,4	2,7	2,4	2,4	2,5
power density (kW/m^2)	11,9	11,4	9,6	9,9	12,8	10,6	9,4	10,7
actual mean speed (m/s)	2,6	2,6	2,4	2,4	2,7	2,4	2,4	2,5
observed power density	10,5	10,2	8,8	9,0	11,7	8,9	8,9	9,9

Finishing with Lefkoşa, as shown in Table 6.7 c and k values are slightly changing. The range of k parameter variation in Lefkoşa is between 4.5 and 8.6 in 2014 and 2015, respectively. Scale parameter on the other hand, is fluctuating between 2.6 and 2.9.

6.5 Wind Speed at Different Heights

All wind speeds analyzed in this work up to this point were captured at a height of 10 m as mentioned before. To generate electrical energy using wind turbines, the knowledge of wind speed at relative wind turbine hub height is essential for power assessment. Using power law expression presented in equation (5.1), the wind speeds for each location was extrapolated and the mean yearly resulting wind speeds at different heights are shown in the figures below. The heights were selected based on the hub height of wind turbines used in the economic assessment.

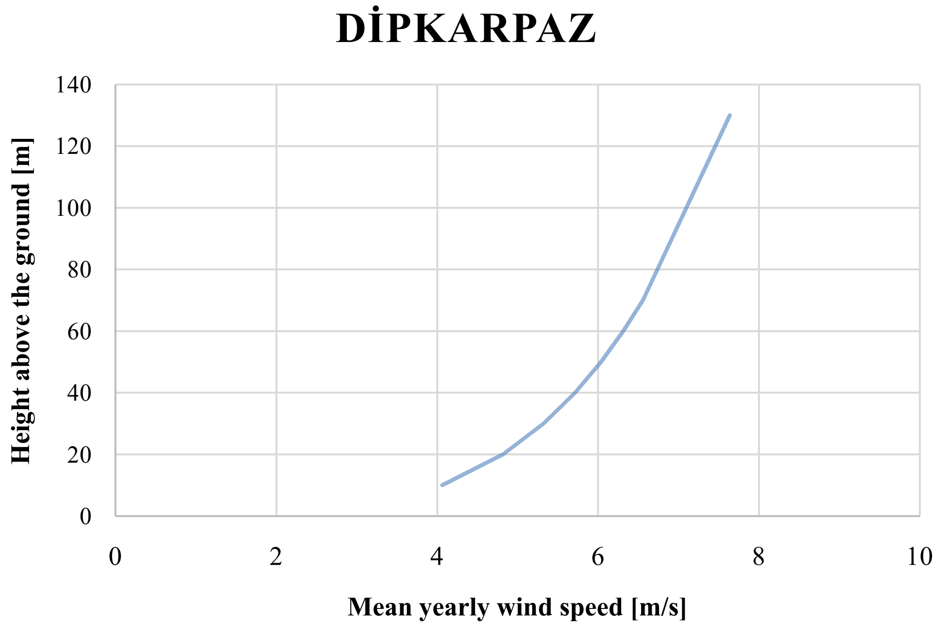

Figure 6.33: Mean yearly wind speeds at different heights in Dipkarpaz

Starting with Dipkarpaz, the mean overall wind speed at 10 m height is about 4.1 m/s. after extrapolating the speed on a 10 m step up to a height of 70 m, the average increase rate in the speed is around 41%, while, the speed at a height of 130 m equals 7.6 m/s.

In Figure 6.33, the extrapolated mean yearly wind speeds for Ercan location is presented. It can be noticed that the rate of increase with respect to height is less than the one in Dipkarpaz which is 38%. The speed at 130 m is about 7 m/s. These values are the mean of all year's values at the same height. The difference between the speed at 10 m and 20 m (≅ 0.9 m/s) is the maximum difference with respect to the height difference. A similar case is also noticed in Dipkarpaz with a deference equal 0.75 m/s.

At Gazimağusa, as shown in Figure 6.34, the mean yearly increase rate is 39% which can be considered similar to the one at Ercan. Also at this location, the same pattern can be noticed for the biggest difference between the speed at 10 m and 20 m heights.

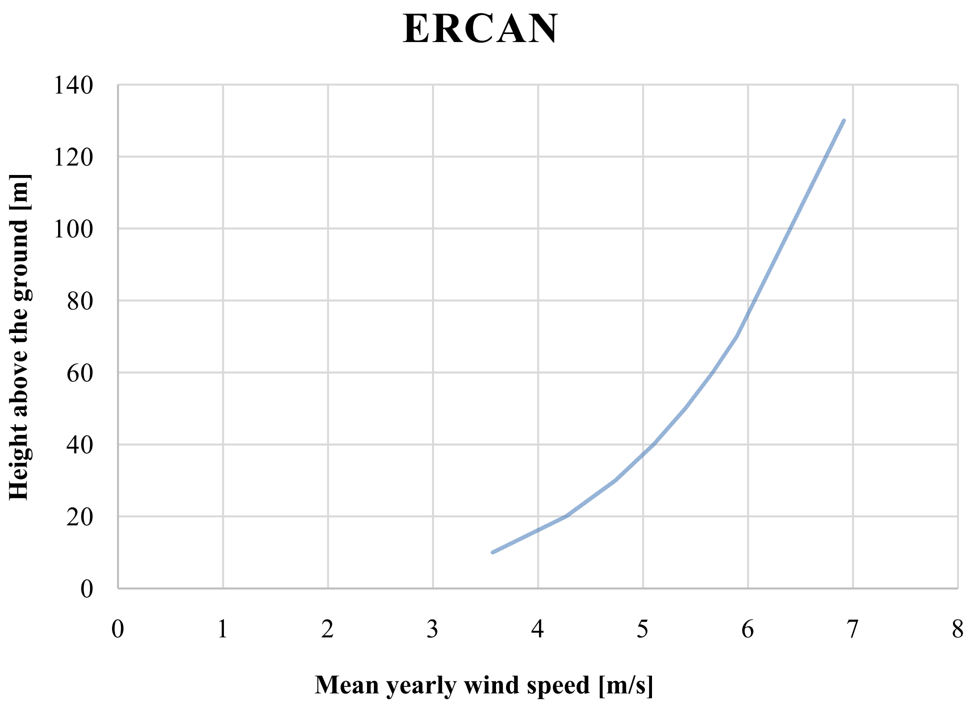

Figure 6.34: Mean yearly wind speeds at different heights in Ercan

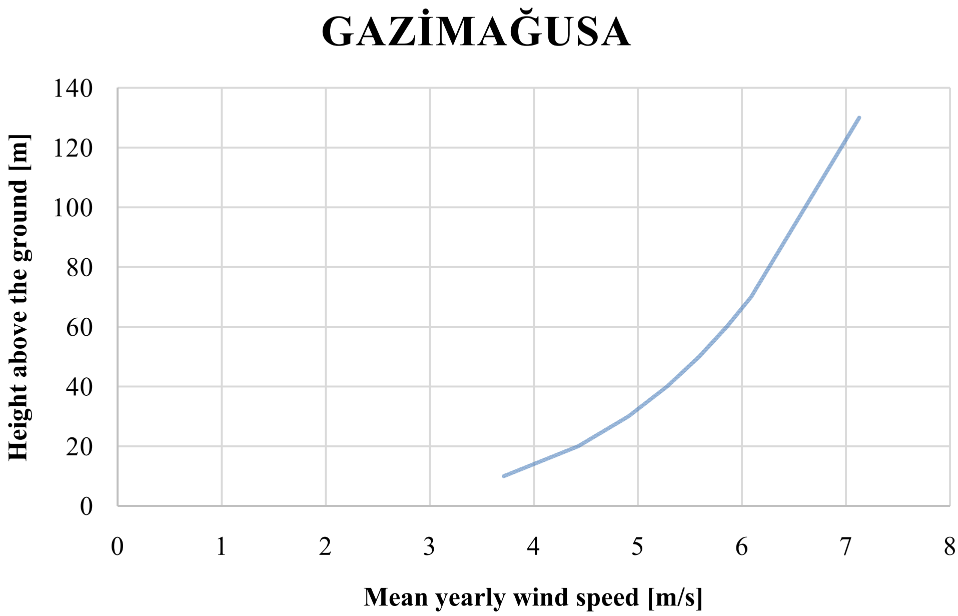

Figure 6.35: Mean yearly wind speeds at different heights in Gazimağusa

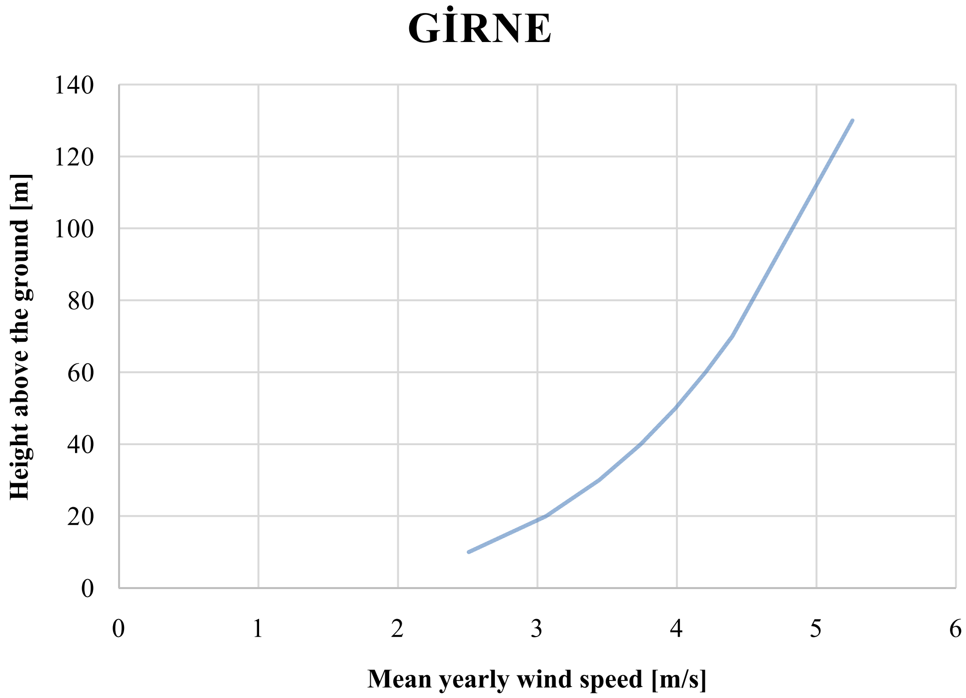

Figure 6.36: Mean yearly wind speeds at different heights in Girne

Reaching to Girne location, wind speed behavior with height increase became obvious. The speed difference increases the most at a height of 20 m, afterward; a steady increase is noticeable for the higher altitudes. The average increase rate at Girne is 32%.

Figure 6.36, illustrates the mean yearly wind speeds at different heights in Güzelyurt. Average increase rate is calculated to be 32%, which is equal to the average change rate in Girne. The increase rate is in not the only thing in common between Girne and Güzelyurt; the speeds are nearly equal to each other at each height.

At Lefkoşa, the minimum average increase rate can be found (31%). It also has approximately similar mean speed values of those in Girne and Gazimağusa.

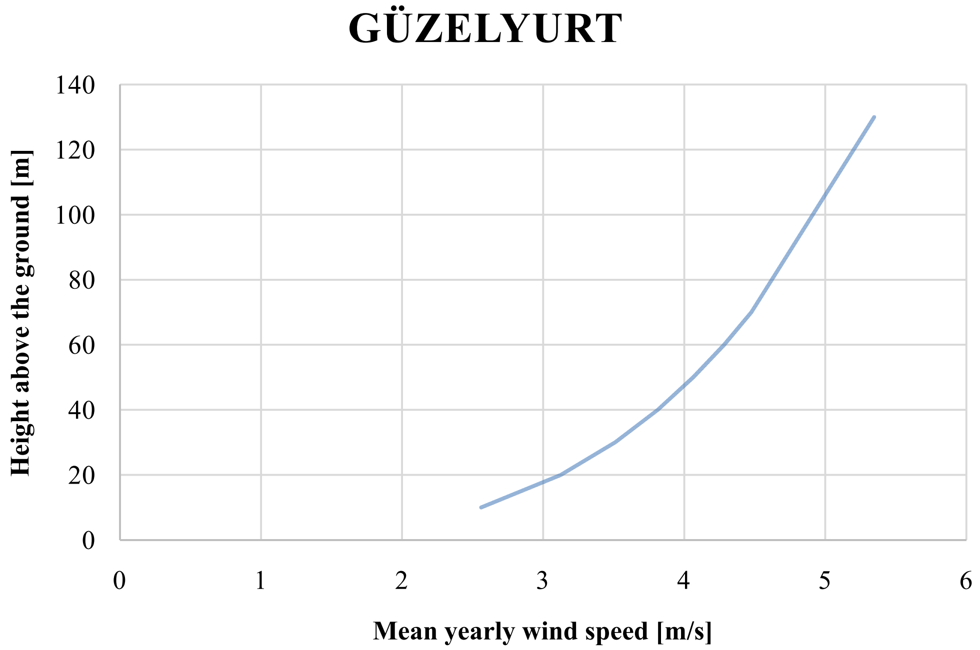

Figure 6.37: Mean yearly wind speeds at different heights in Güzelyurt

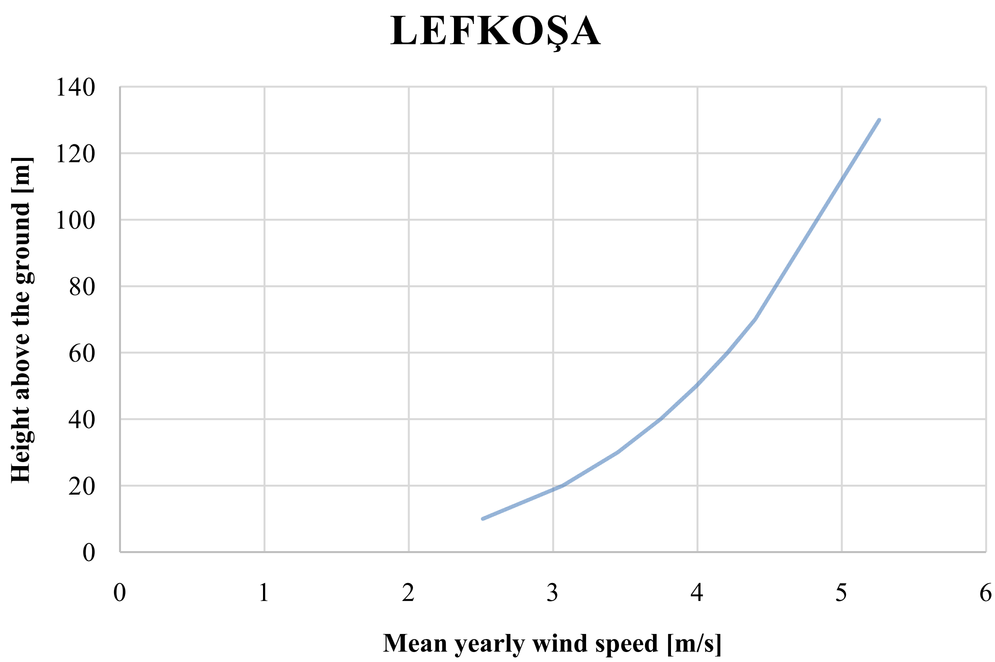

Figure 6.38: Mean yearly wind speeds at different heights in Lefkoşa

6.6 Capacity Factors of Selected Wind Turbines

The capacity factors of all turbines in studied areas which calculated using equation (5.4) are presented in Table 6.8. The results show that the highest capacity for all turbines is obtained in Gazimağusa site. On the other hand, Girne has the lowest capacity factor for all turbines used in the analysis.

Table 6.8: Selected turbines capacity factors (C_f %)

Turbines	Dipkarpaz	Ercan	Gazimağusa	Girne	Güzelyurt	Lefkoşa
Aircon10	23,36	20.18	25,12	6,34	7,09	10,52
EolSenegal 500	69,55	55.14	72,50	36,59	40,77	39,78
Finn Wind Tuule C 200	60,41	46.14	62,77	34,09	37,43	35,82
P10-20	28,60	20.70	28,96	5,98	7,73	11,09
EWT DW	24,36	18.65	30,75	7,50	9,26	12,88
Enercon E33	34,92	22.98	35,28	12,30	14,05	17,41
P-15-50	32,52	19.37	33,90	10,48	12,65	15,63
DW61-900 kW	21,28	18,38	22,88	5,77	7,08	9,58
Enercon E53	16,47	14,88	17,71	4,47	5,48	7,42
Enercon E82	17,87	15,44	19,22	4,85	5,94	8,05

In all locations, the highest capacity factor is obtained in Gazimağusa by EolSenegal 500 wind turbine is 72.5%, while, the lowest value can be seen in Girne as 4.47% obtained by Enercon E53 wind turbine.

6.7 Wind Turbine Electricity Generation Cost

Table 6.9 shows the average UCE per kW h foe selected wind turbines for all locations. EolSenegal 500 turbine has the highest UCE per kW h among all selected turbines in all locations. While Enercon E82 turbine, on the other hand, has less UCE per kW h values.

Table 6.9: Average UCE per kW h of all selected turbines in all locations (US$/kW h)

Turbines	Dipkarpaz	Ercan	Gazimağusa	Girne	Güzelyurt	Lefkoşa
Aircon10	0,0202	0,0859	0,0188	0,0745	0,0667	0,0449
EolSenegal 500	0,0566	0,1019	0,0543	0,1076	0,0966	0,0990
Finn Wind Tuule C 200	0,0109	0,0184	0,0104	0,0193	0,0175	0,0183
P10-20	0,0083	0,0351	0,0076	0,0305	0,0248	0,0184
EWT DW	0,0004	0,0016	0,0003	0,0015	0,0012	0,0008
Enercon E33	0,0003	0,0012	0,0002	0,0011	0,0009	0,0007
P-15-50	0,0028	0,0118	0,0026	0,0103	0,0084	0,0062
DW61-900 kW	0,0001	0,0006	0,0001	0,0005	0,0004	0,0003
Enercon E53	0,0002	0,0009	0,0001	0,0008	0,0006	0,0005
Enercon E82	0,0001	0,0003	0,0001	0,0003	0,0002	0,0002

For selected wind turbines classified as micro or small-sized, the lowest cost for unit electricity generation per kW h is offered by the P10-20 wind turbine. For large size classified wind turbines, Enercon E82 has the lowest cost per kW h among all other. Taking the capacity factors, cost and rated power of wind turbines in account it can be said that, the most suitable location for generating electricity by wind turbines with high capacity factor and low cost is Gazimağusa using Enercon E33 wind turbine, which has a capacity factor of around 35.3% and unit cost per kW h equal to 0.00027 US$/kW h.

CHAPTER 7
CONCLUSIONS & RECOMMENDATIONS

7.1 Conclusions

The key findings and conclusions of this study are:

- To evaluate the wind potential in a location, the period of data collection is essential for achieving trustworthy results. As explained in section 6.1, the wind speed can express a tremendous changes by years, for example at Gazimağusa between 2009 and 2010 the mean wind speed increased from 3.1 m/s to 4.7 m/s. in other words, if a data of the period (2000-2009) used for the analysis purpose, then, Gazimağusa location would have been considered as a non-favorable location in terms of wind potential.

- Based on the results, Weibull distribution function proved to be better than Gamma function in terms of accuracy for the given speed data with RSQ value of 96%.

- For considered locations, the range of monthly wind speed is between 2.3 and 6.2 m/s in Dipkarpaz, between 1 and 4.8 m/s in Ercan, between 2.3 and 7.2 m/s in Gazimağusa, between 1.1 and 4.6 m/s in Girne, between 1.1 and 3.6 m/s in Güzelyurt and between 1.5 and 3.5 m/s in Lefkoşa.

- Average yearly Weibull wind power density for the selected locations is found to be the highest in Dipkarpaz with a value equal to 46 kW/m^2 followed by Gazimağusa with a mean value of 37.8 kW/m^2, Ercan comes third with a value equals 29.8 kW/m^2, while, Lefkoşa, Girne and Güzelyurt have a low average wind power density with a values equal to 10.8, 10.9 and 11 kW/m^2, respectively.

- Average Weibull scale parameters values are 4.88, 4.43, 4.27, 2.70, 2.67 and 2.56 m/s in Gazimağusa, Dipkarpaz, Ercan, Lefkoşa, Güzelyurt and Girne, respectively.

- The highest capacity factor for all turbines is obtained in Gazimağusa site. On the other hand, Girne has the lowest capacity factor for all turbines used in the analysis.

- the most suitable location for generating electricity by wind turbines with high capacity factor and low cost is Gazimağusa using Enercon E33 wind turbine, which has a capacity factor of around 35.3% and unit cost per kW h equal to 0.00027US$/kW h.

7.2 Recommendations

At the end of the study, the following future studies are recommended:

- Using an hourly wind speeds data, the yearly operation hours of wind turbines can be calculated and used to study the real effect of electricity generating by wind turbines on electricity demand curve of Northern Cyprus.

- The relationship between wind speed and temperature, air humidity and density can be investigated to help indicate the wind speed behavior in the future.

- Other renewable energy options can be compared with the study conducted in this thesis to select the best alternative of electricity generating by fossil-fueled plants.

- Designing a wind farm in the selected location and conducting deep economic analysis is also desirable.

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APPENDICES

APPENDIX 1

SELECTED TURBINES CATALOGUES

1. AIRCON 10 S - 9,80 kW - Wind turbine. (n.d.). Retrieved June 4, 2018, from https://www.bing.com/cr?IG=67663A42C6A54C02A55AE8ED03FFA2F0&CID=26D0F6288DFE6F071EDEFA2C8C036E6D&rd=1&h=CR8j-XOJjYYWDs71gEjUjlJ55aYAqcwXF8PE5Up787s&v=1&r=https://en.wind-turbine-models.com/turbines/157-aircon-10-s&p=DevEx.LB.1,5507.1

2. Network, W. T. (n.d.). 500W-1000W. Retrieved June 4, 2018, from http://vertical-windturbine.com/500-1000/index.html

3. Finn wind tuuleCatalog c 200 Small. (n.d.). Retrieved June 4, 2018, from https://es.scribd.com/doc/296090028/wind-tuule-Catalog-FINAL-Small

4. CATALOGUE - folkecenter.eu. (n.d.). Retrieved June 4, 2018, from http://www.bing.com/cr?IG=DCCAC9ECD3DF4F9CA7C9ECBA5FE0535E&CID=26558467EE3862AE011E8863EFC563B3&rd=1&h=QLbTnECOQE-3P0HXtmMBHNuQ1KJQy9E1fiQzbH5N9BA&v=1&r=http://www.folkecenter.eu/PDF/Preview-Catalogue-Small-Wind-Turbines.pdf&p=DevEx.LB.1,5065.1

5. Wind turbines - ewtdirectwind.com. (n.d.). Retrieved June 4, 2018, from http://www.bing.com/cr?IG=8F5E45F0B8334A319AD1075EC2BCBA06&CID=2541090562FD68470F62050163006999&rd=1&h=Raf4V8WiA1fGFSw8poQ5AdYrNKKOvjYx-7N5WDmte_M&v=1&r=http://ewtdirectwind.com/turbines/&p=DevEx.LB.1,5513.1

6. E-33, E-53, E-82 - Enercon. (n.d.). Retrieved June 4, 2018, from https://www.bing.com/cr?IG=9B26E3255A0E41368A5967C28B9639DA&CID=26D0624D8891618737896E49896C6098&rd=1&h=e2ApcnXoVLmxJVzmNdefknDlIcIA9ZdTzPV1rMNhAPk&v=1&r=https://www.enercon.de/fileadmin/Redakteur/Medien-

Portal/broschueren/pdf/en/ENERCON_Produkt_en_06_2015.pdf&p=DevEx.LB.1,5511.1

7. Wind turbines. (n.d.). Retrieved June 4, 2018, from http://ewtdirectwind.com/wind-turbines/dw61-500kw900kw.html

APPENDIX 2

YEARLY PDF AND CDF CHARTS FOR ALL LOCATIONS

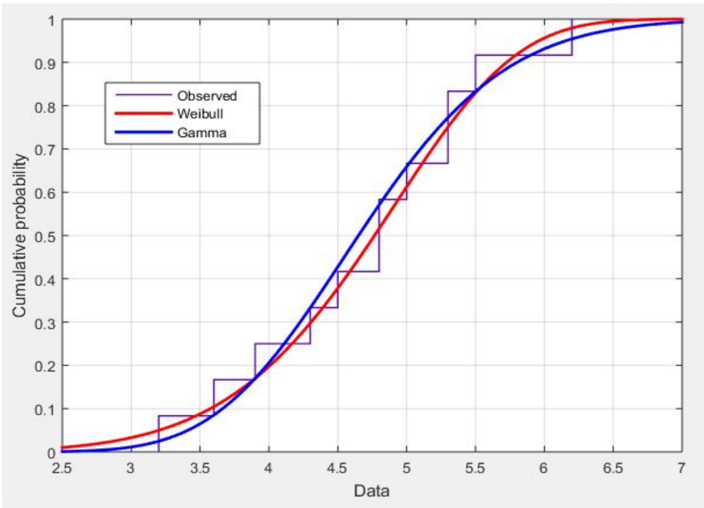


Figure 1: CDF-Dipkarpaz-2005

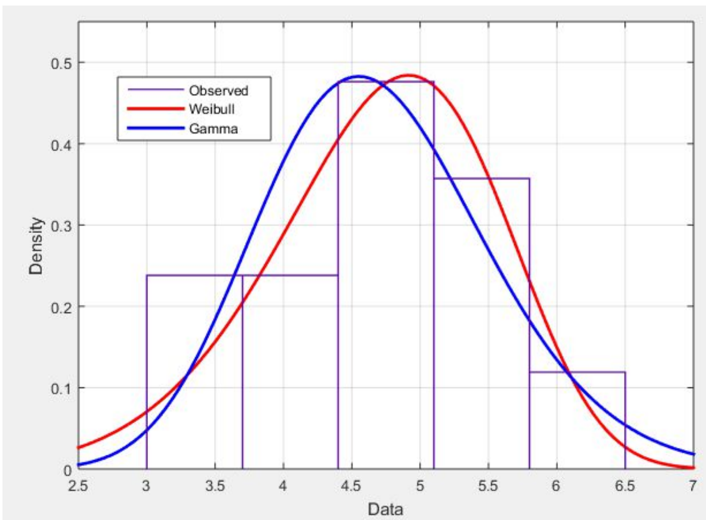


Figure 2: PDF-Dipkarpaz-2005

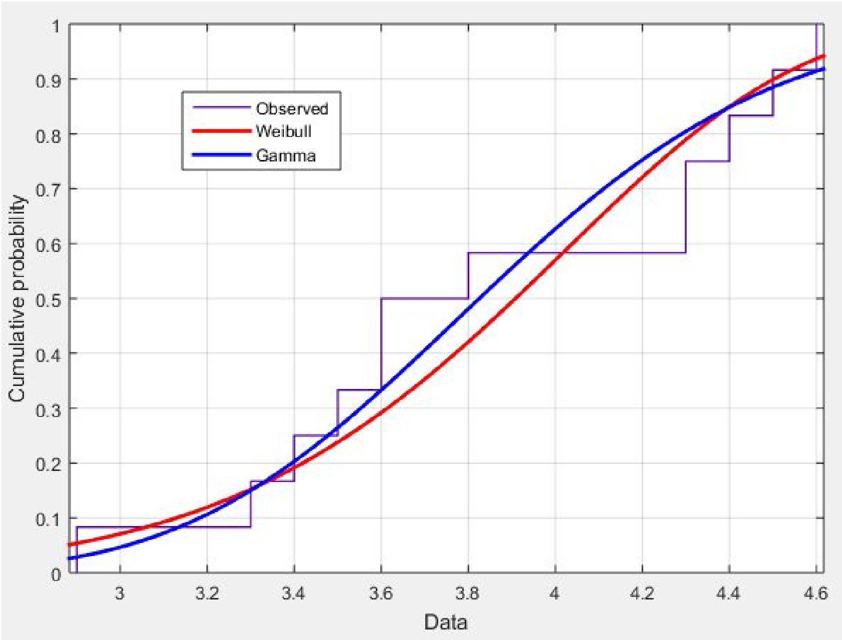


Figure 3: CDF-Dipkarpaz-2006

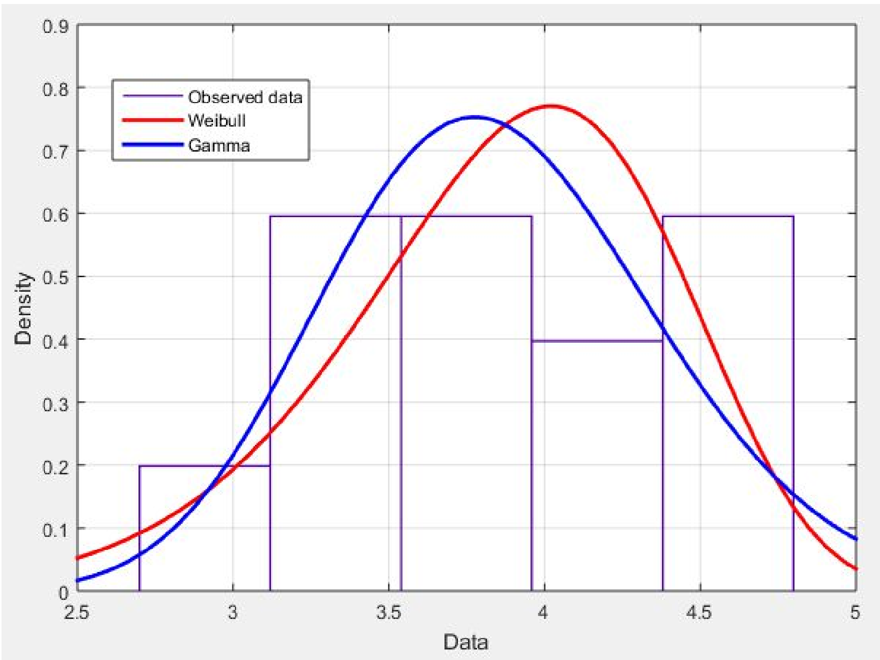


Figure 4: PDF-Dipkarpaz-2006

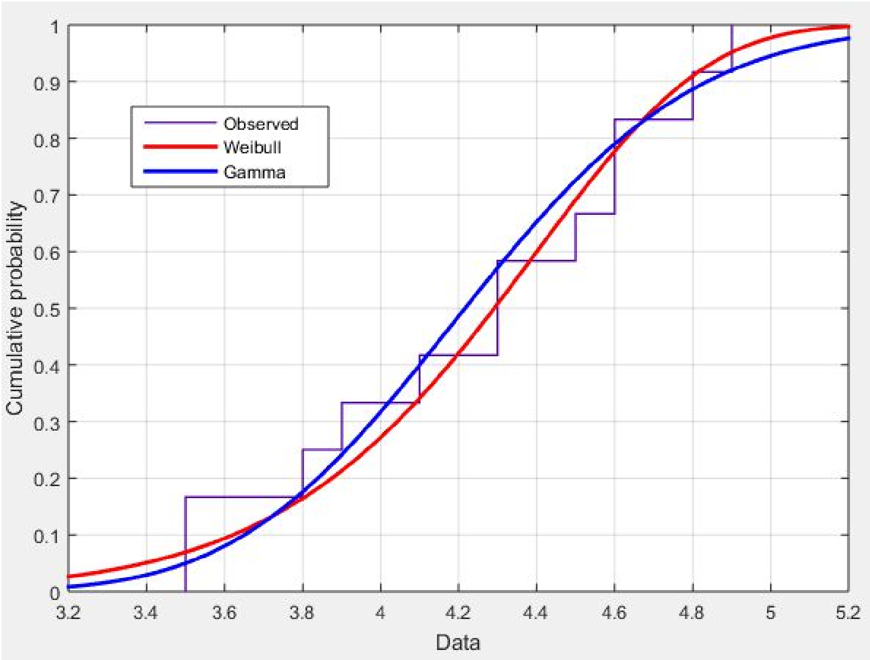


Figure 5: CDF-Dipkarpaz-2007

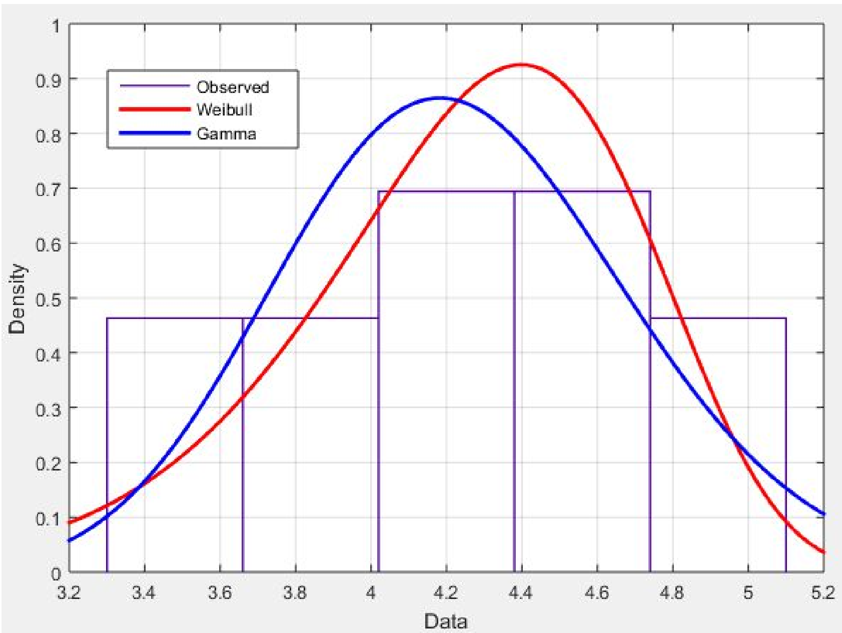


Figure 6: PDF-Dipkarpaz-2007

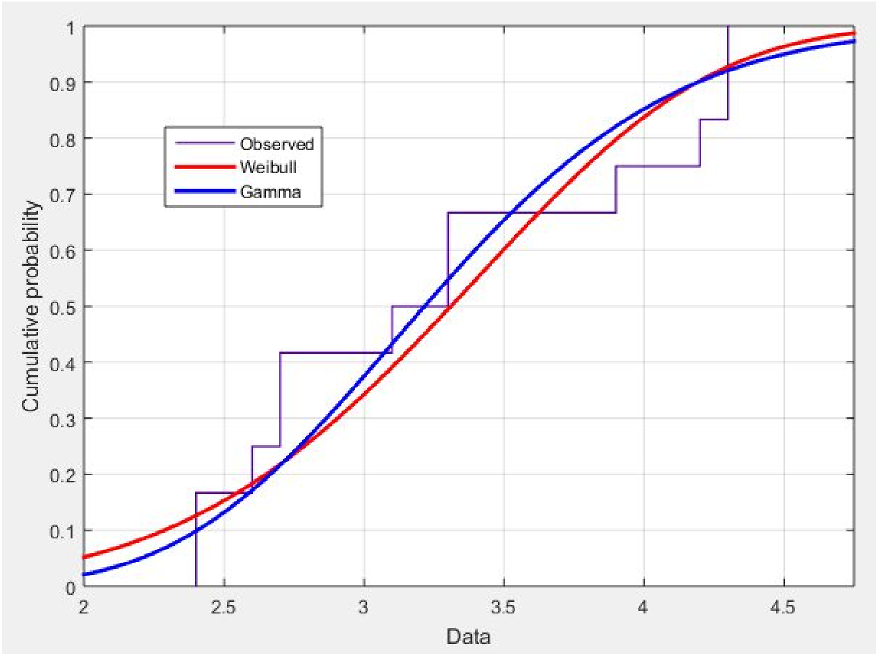


Figure 7: CDF-Dipkarpaz-2008

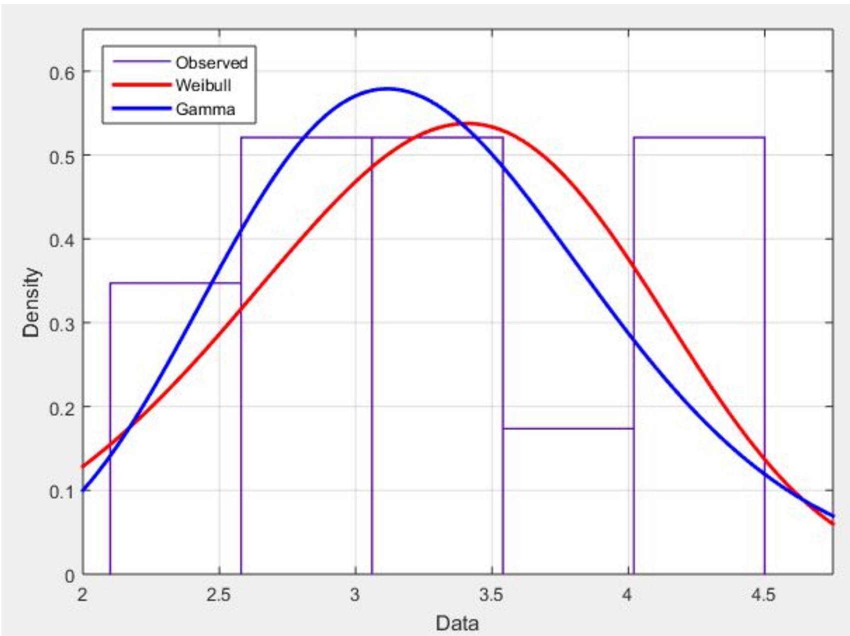


Figure 8: PDF-Dipkarpaz-2008

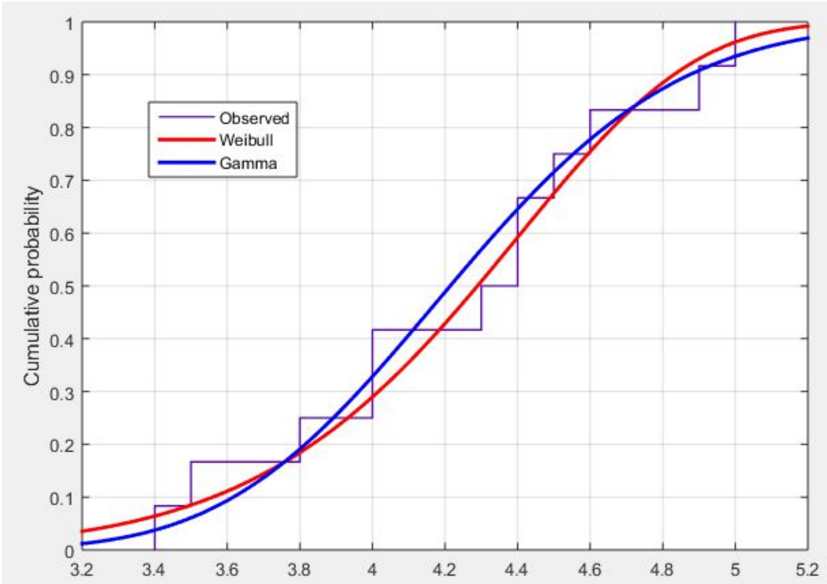


Figure 9: CDF-Dipkarpaz-2009

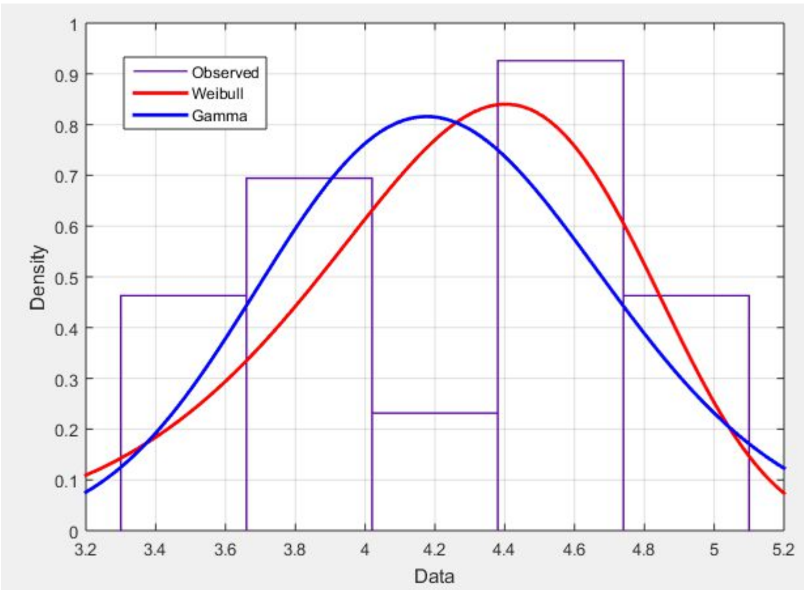


Figure 10: PDF-Dipkarpaz-2009

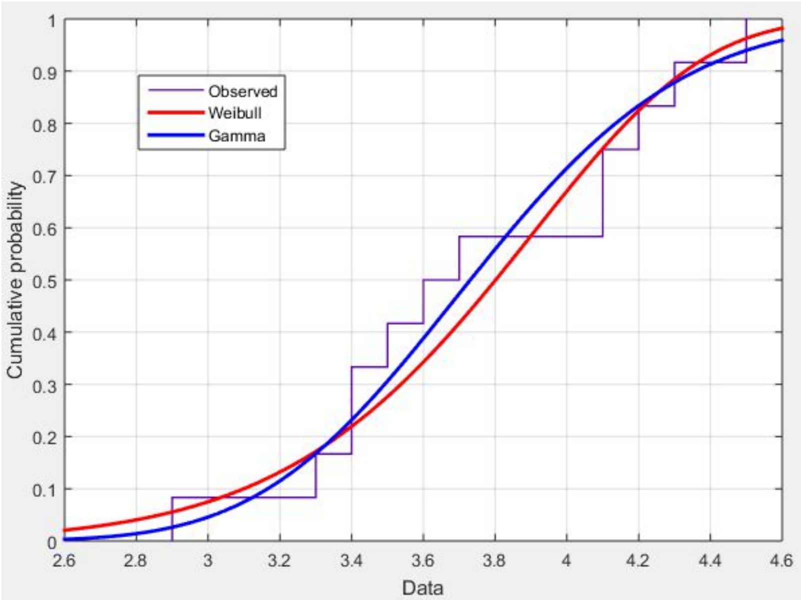


Figure 11: CDF-Dipkarpaz-2010

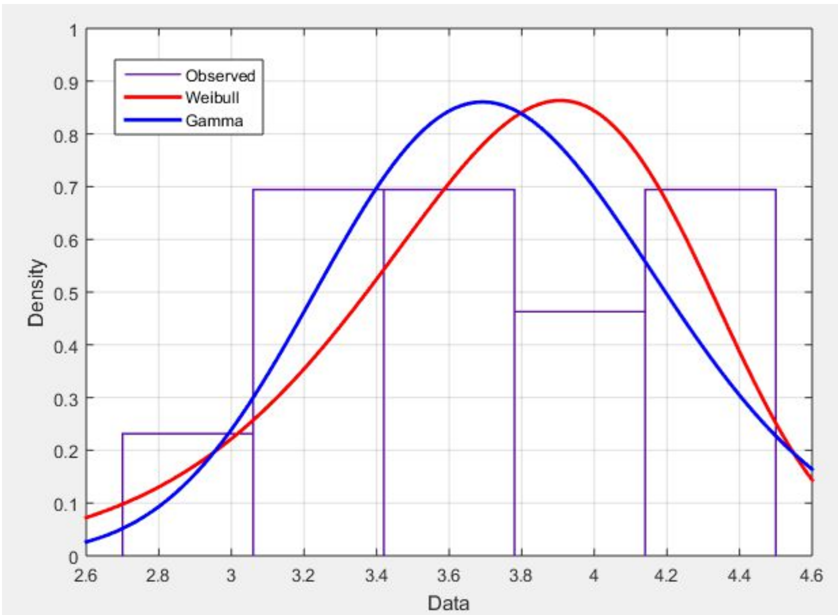


Figure 12: PDF-Dipkarpaz-2010

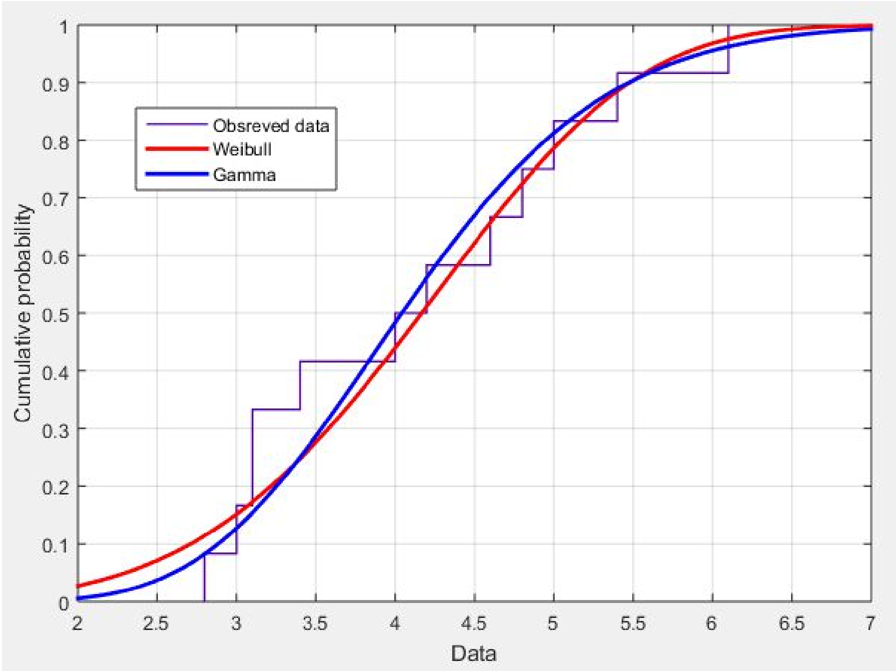


Figure 13: CDF-Dipkarpaz-2011

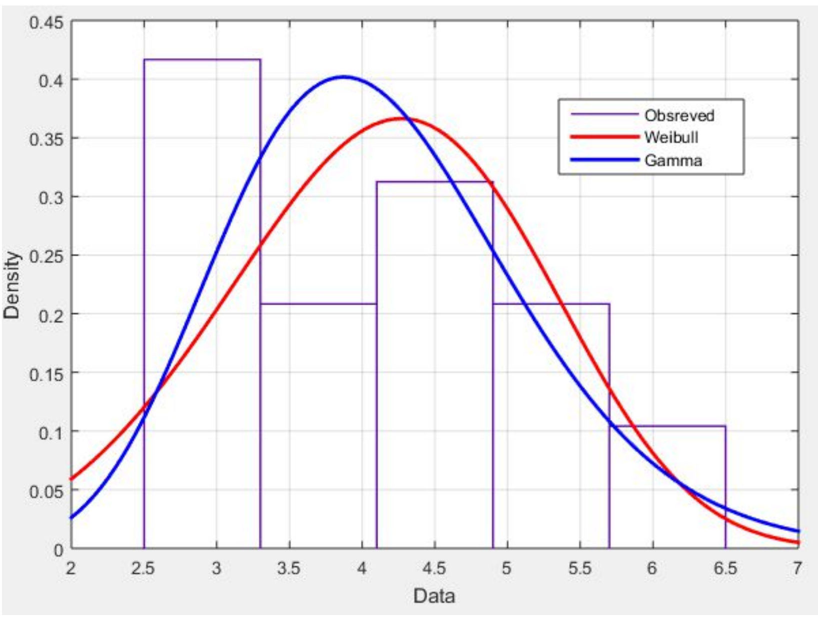


Figure 14: PDF-Dipkarpaz-2011

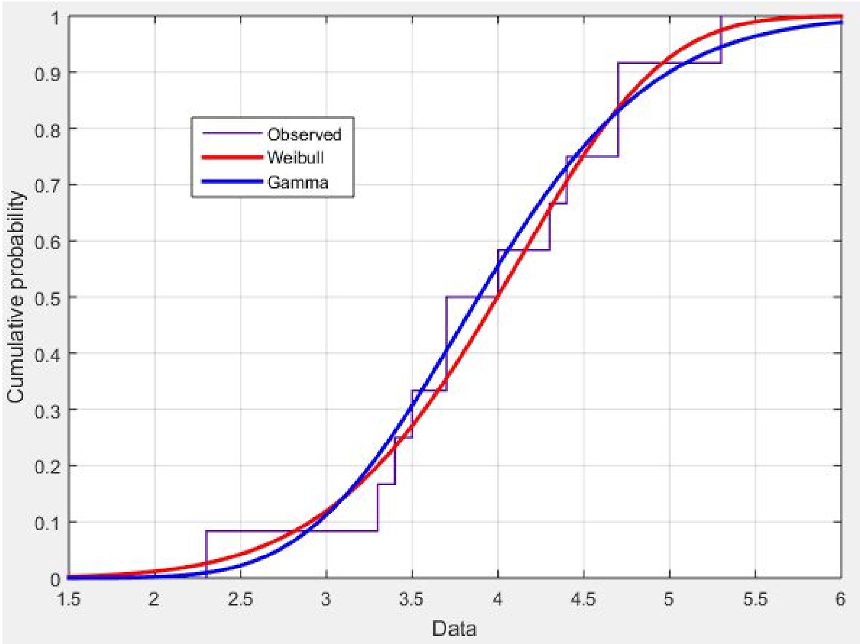


Figure 15: CDF-Dipkarpaz-2012

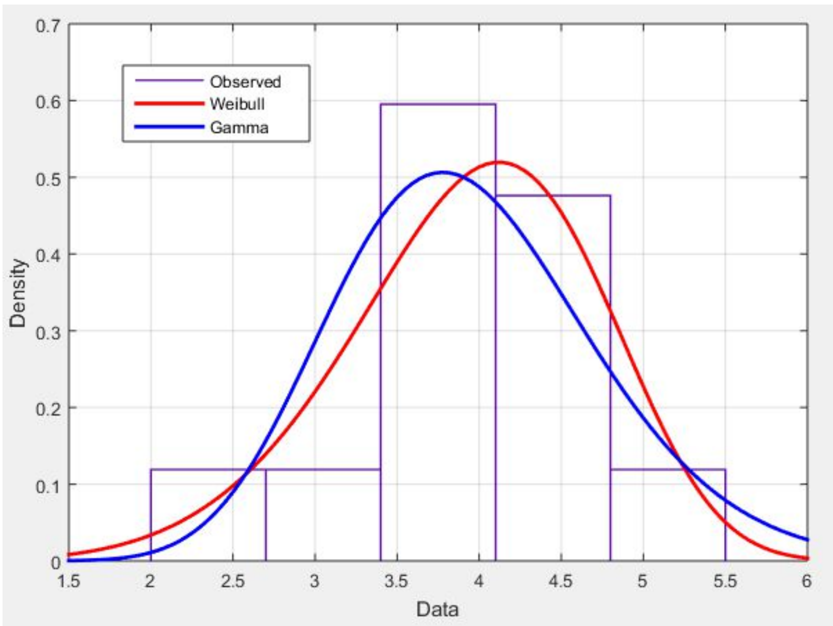


Figure 16: PDF-Dipkarpaz-2012

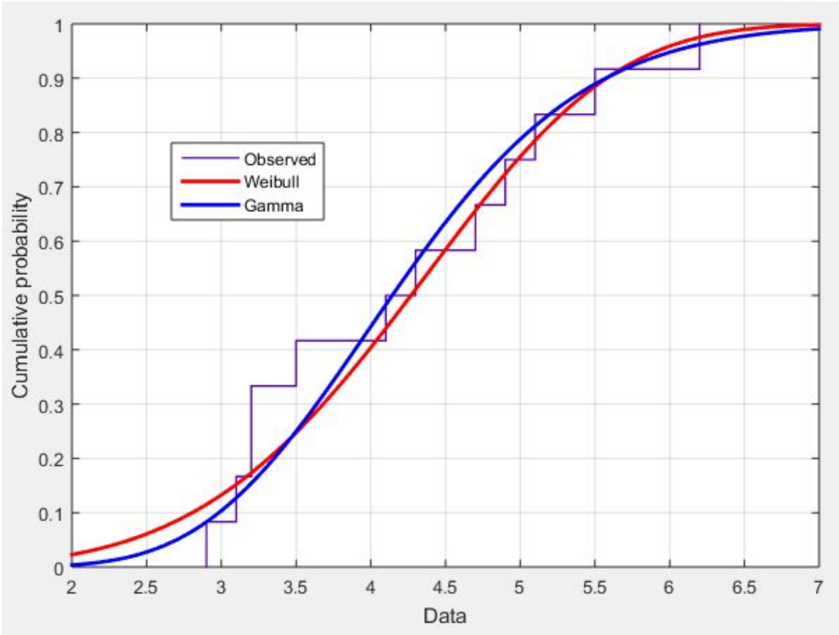


Figure 17: CDF-Dipkarpaz-2013

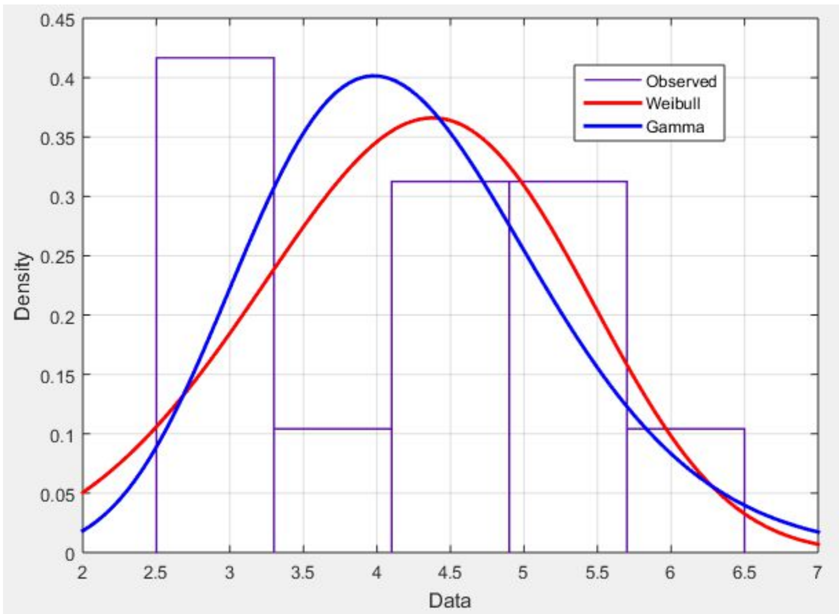


Figure 18: PDF-Dipkarpaz-2013

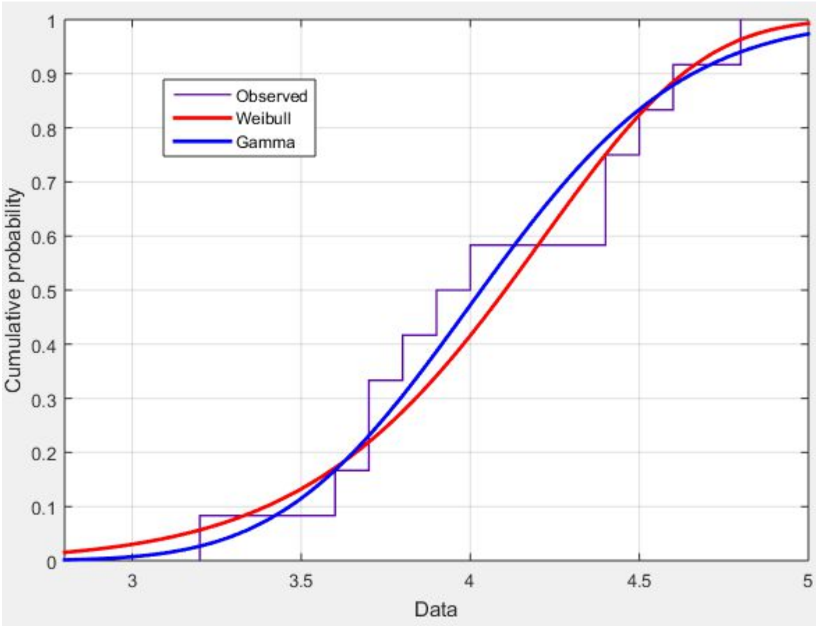


Figure 19: CDF-Dipkarpaz-2014

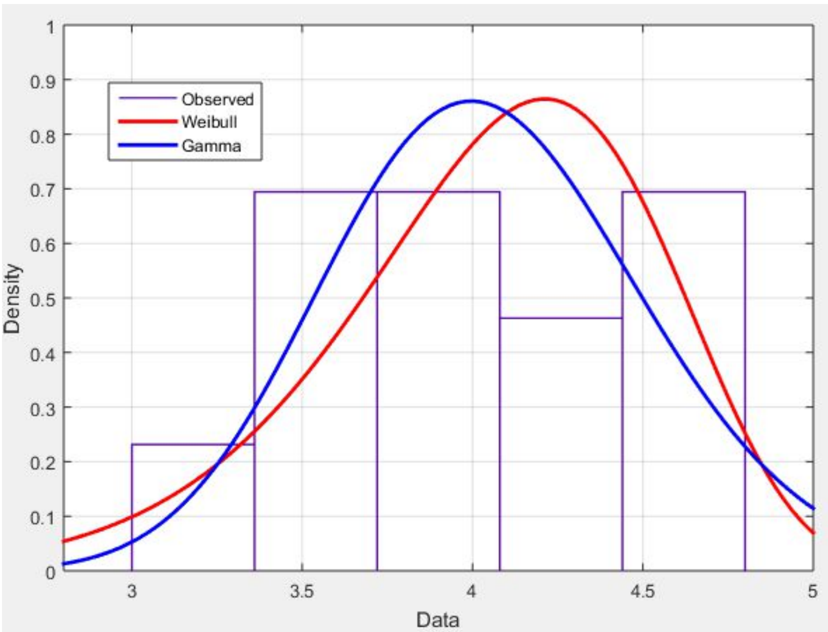


Figure 20: PDF-Dipkarpaz-2014

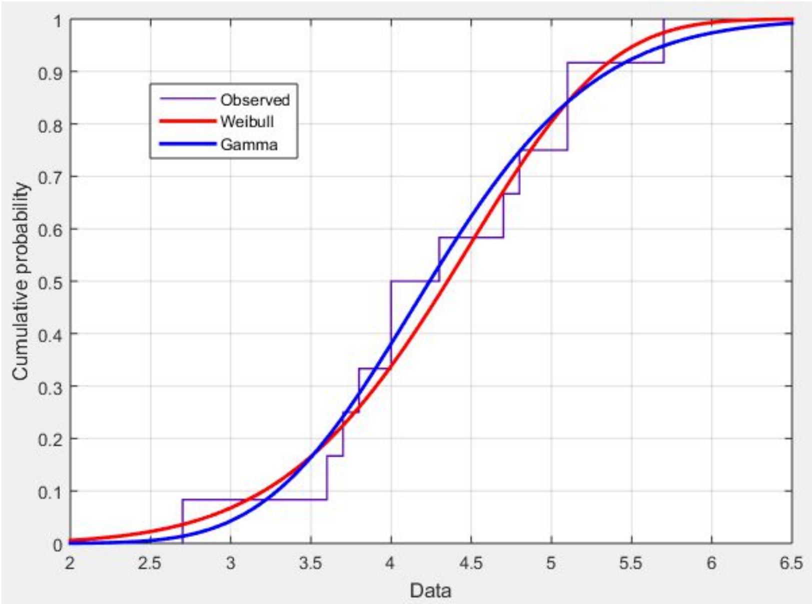


Figure 21: CDF-Dipkarpaz-2015

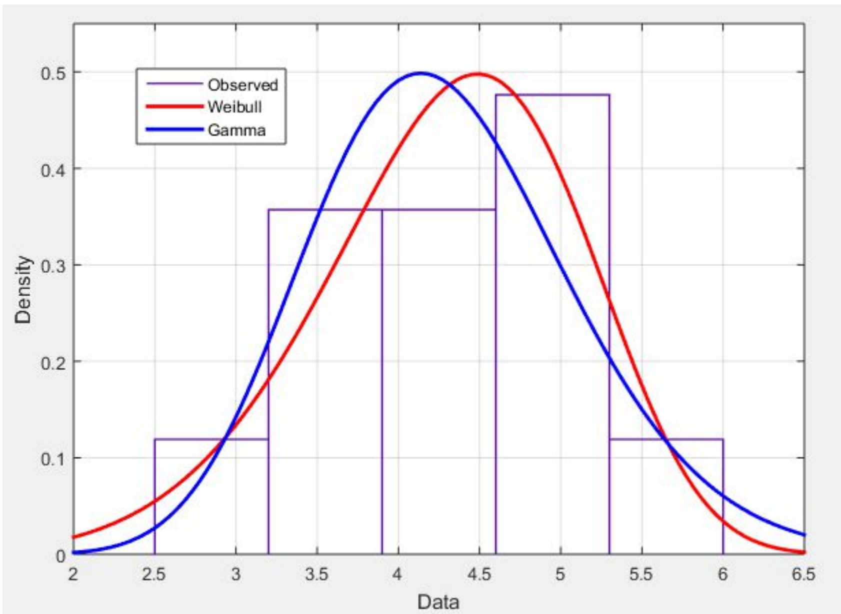


Figure 22: PDF-Dipkarpaz-2015

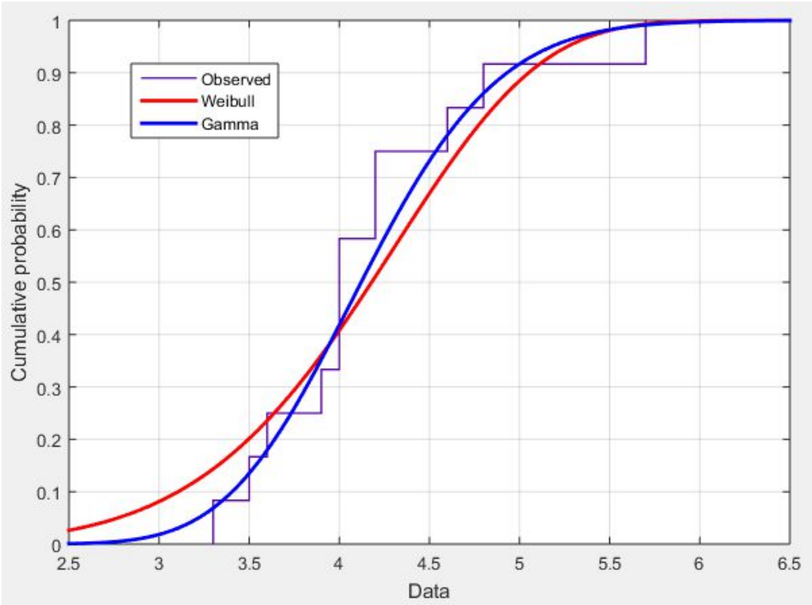


Figure 23: CDF-Dipkarpaz-2016

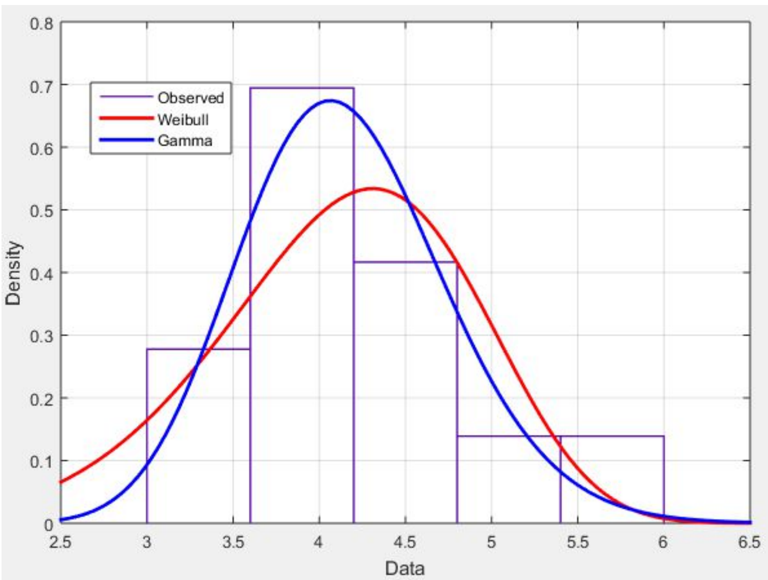


Figure 24: PDF-Dipkarpaz-2016

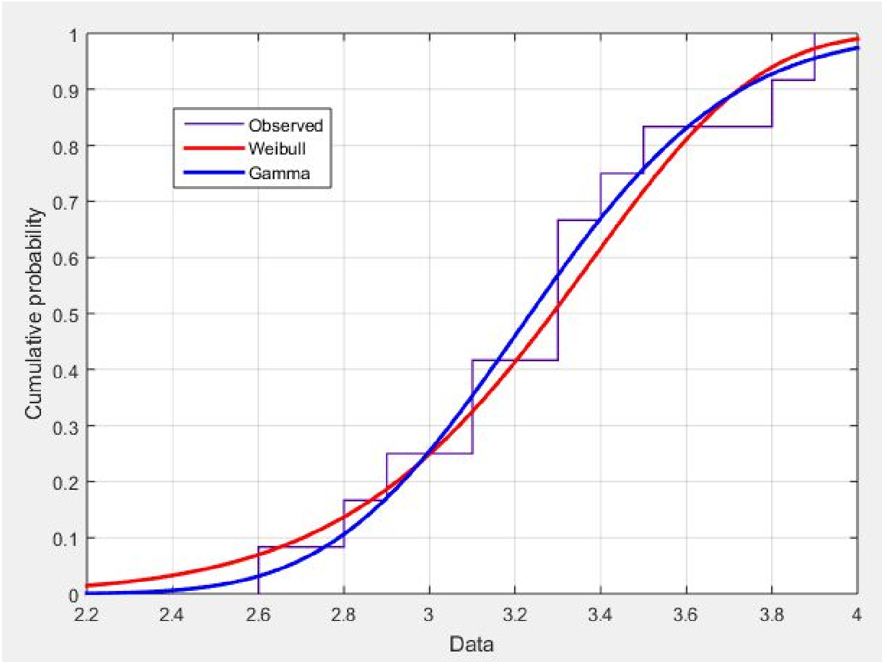


Figure 25: CDF-Ercan-2000

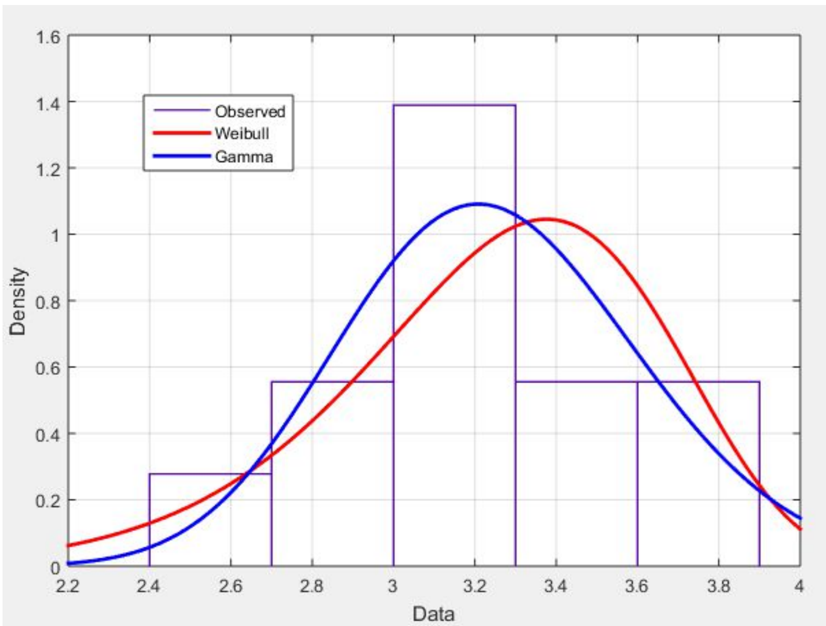


Figure 26: PDF-Ercan-2000

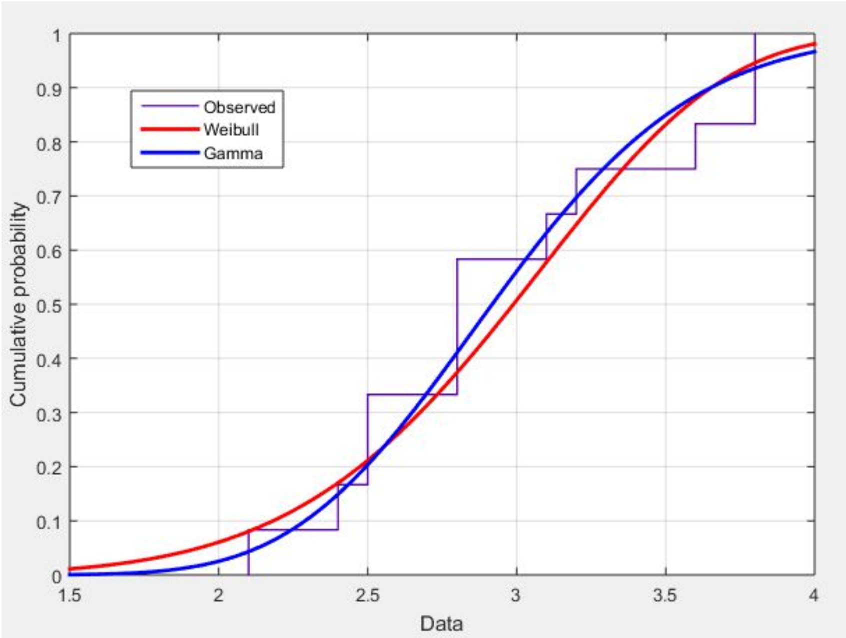


Figure 27: CDF-Ercan-2001

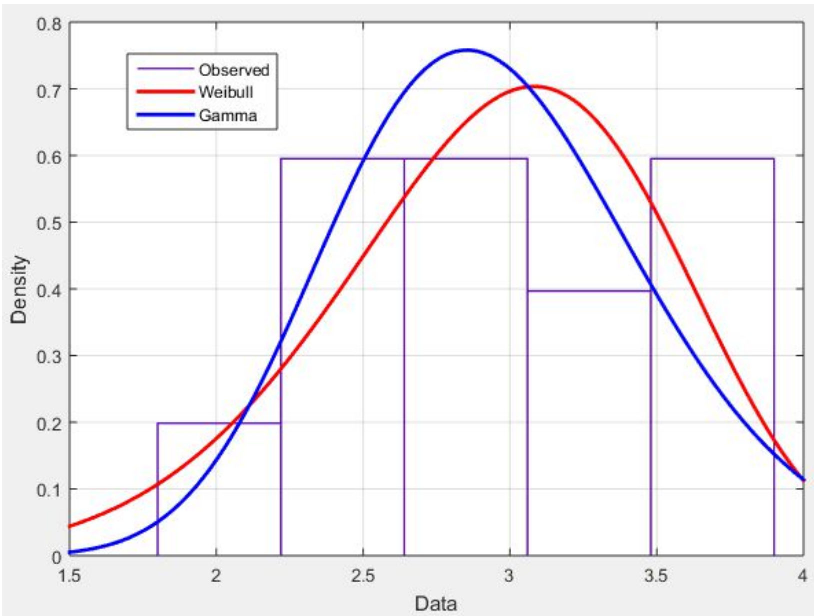


Figure 28: PDF-Ercan-2001

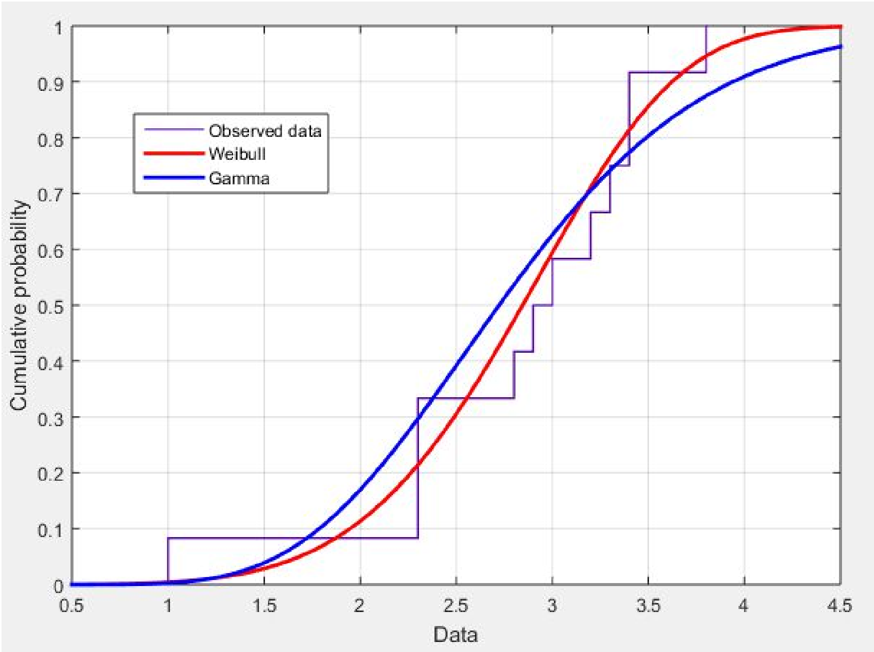


Figure 29: CDF-Ercan-2002

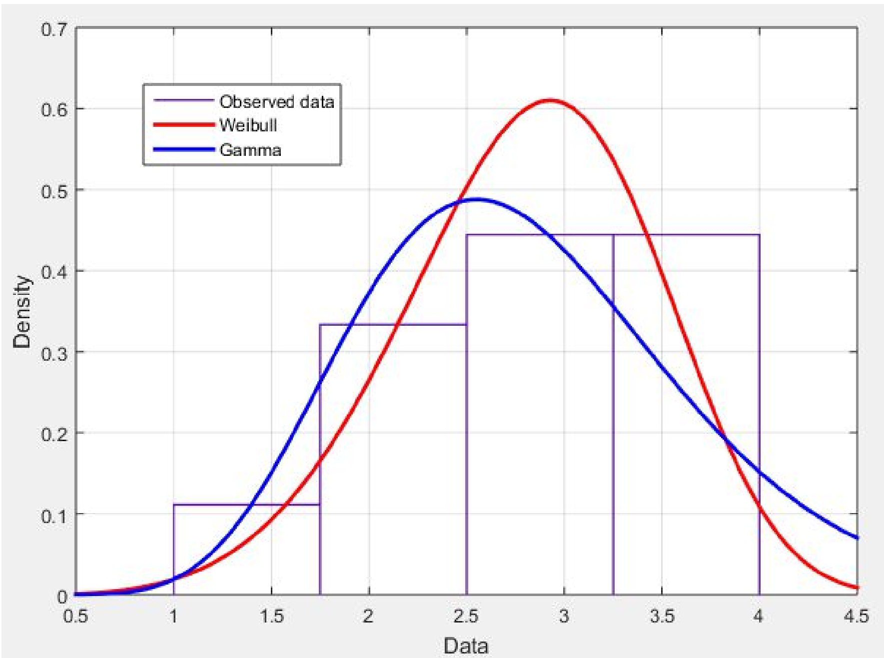


Figure 30: PDF-Ercan-2002

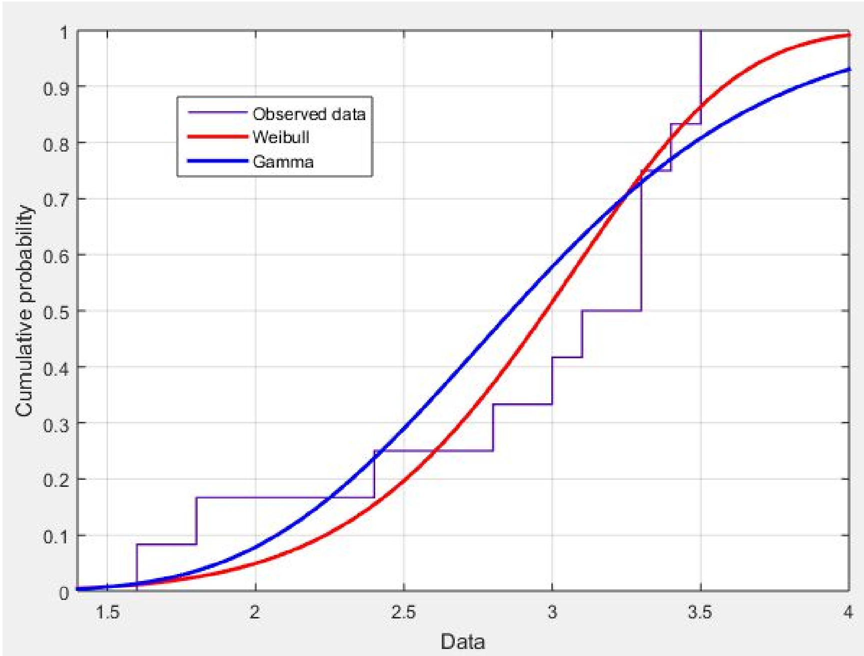


Figure 31: CDF- Ercan -2003

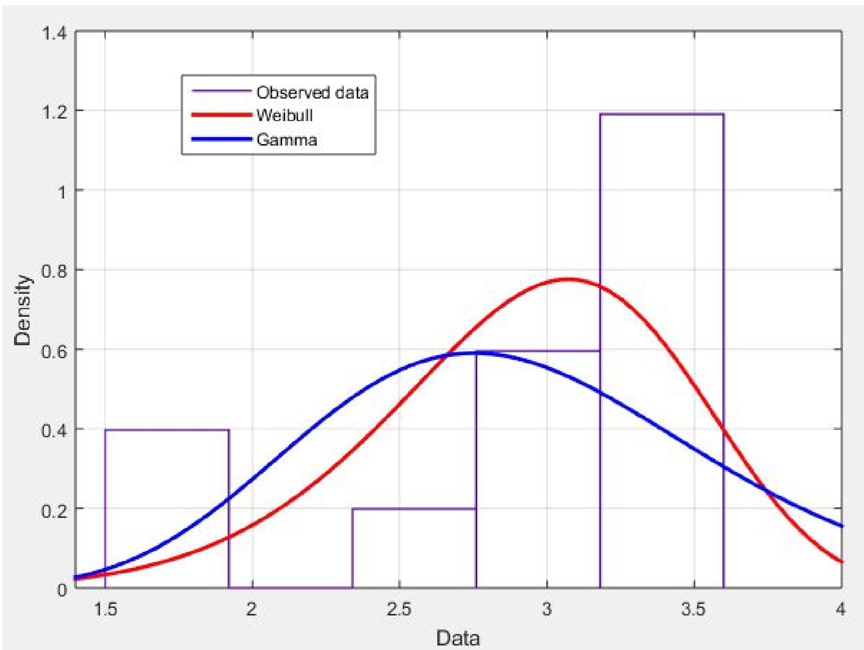


Figure 32: PDF- Ercan -2003

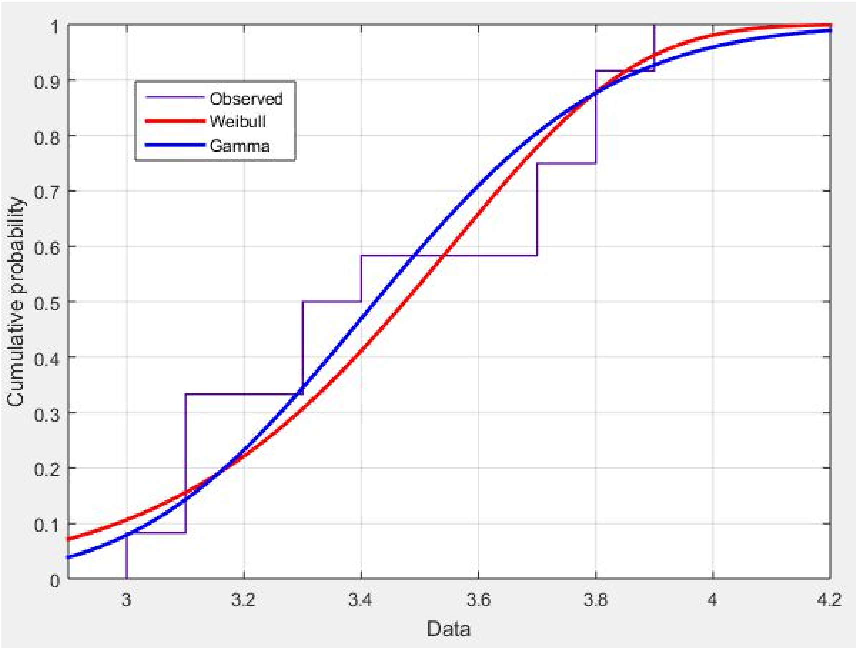


Figure 33: CDF- Ercan -2004

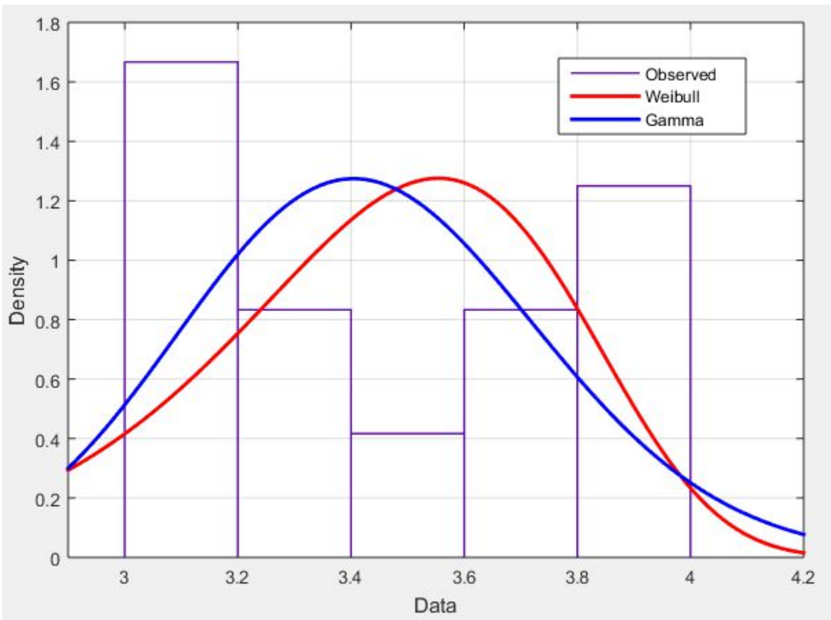


Figure 34: PDF- Ercan -2004

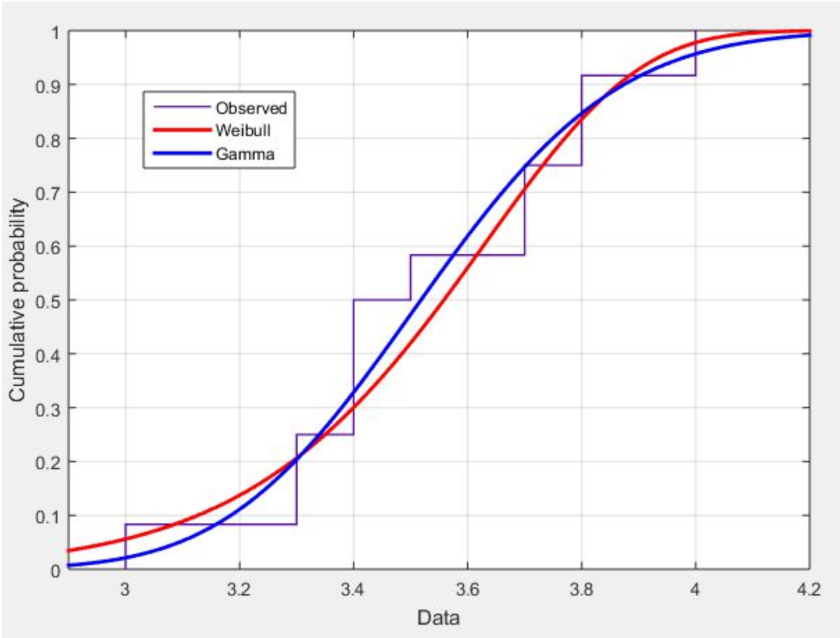


Figure 35: CDF- Ercan -2005

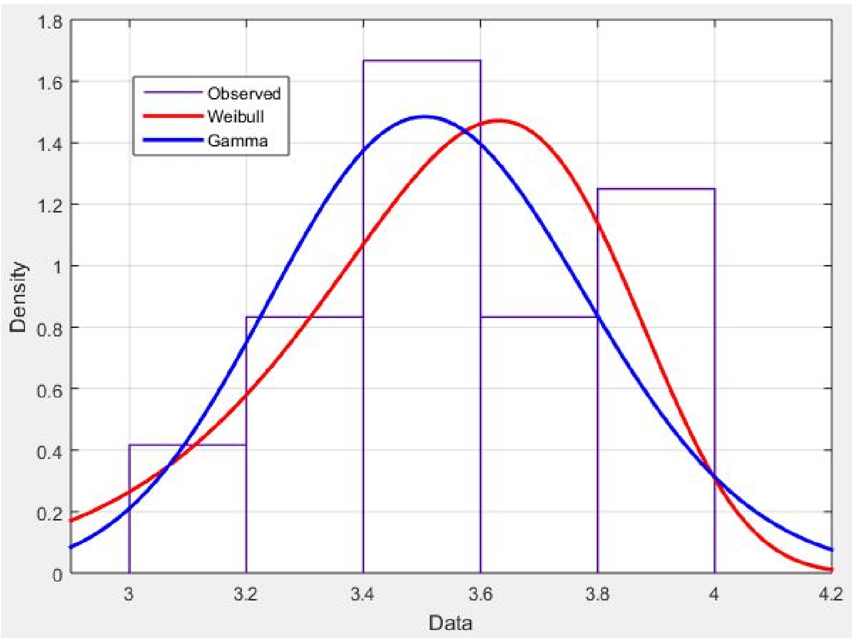


Figure 36: PDF- Ercan -2005

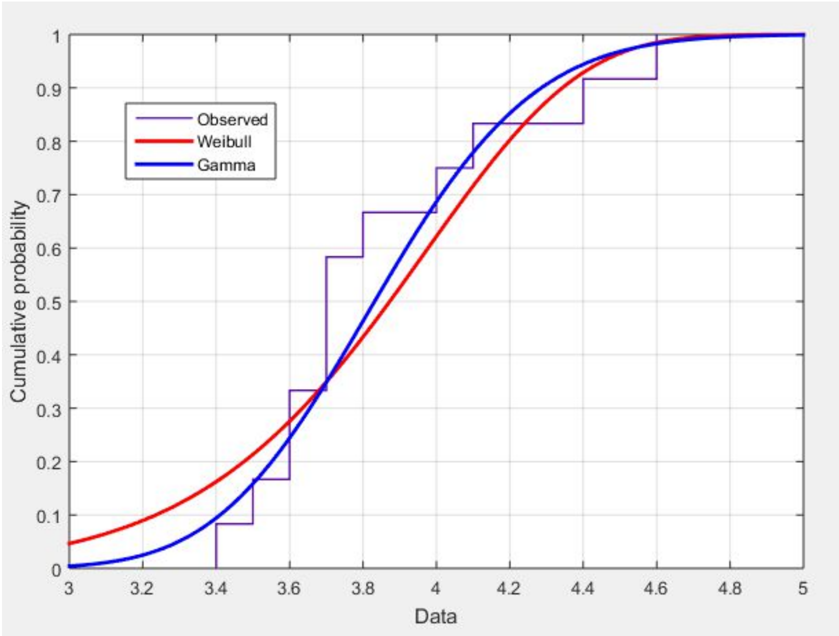


Figure 37: CDF- Ercan -2006

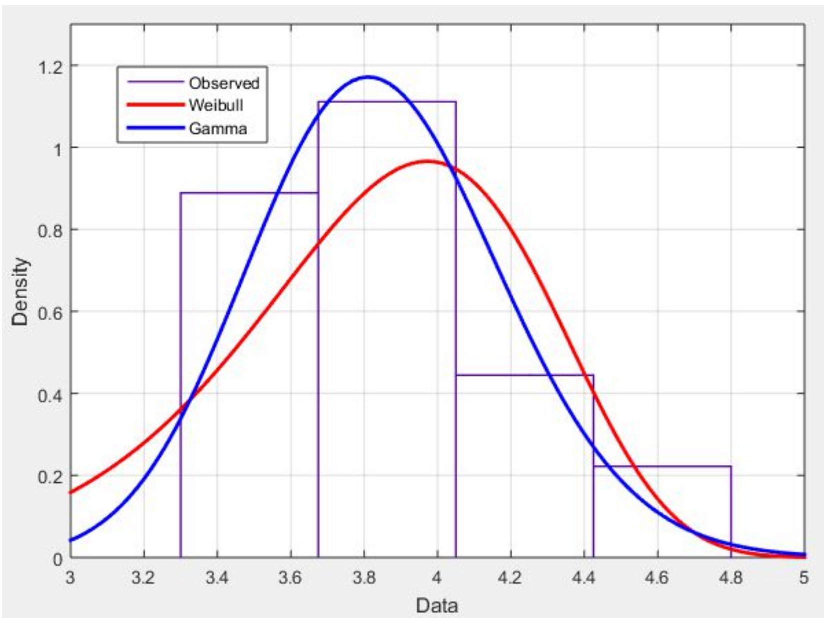


Figure 38: PDF- Ercan -2006

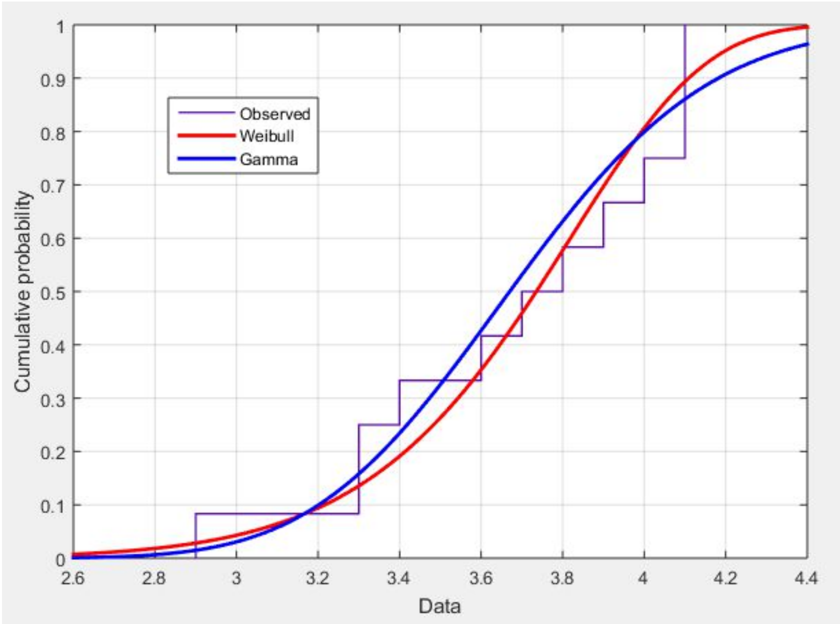


Figure 39: CDF- Ercan -2007

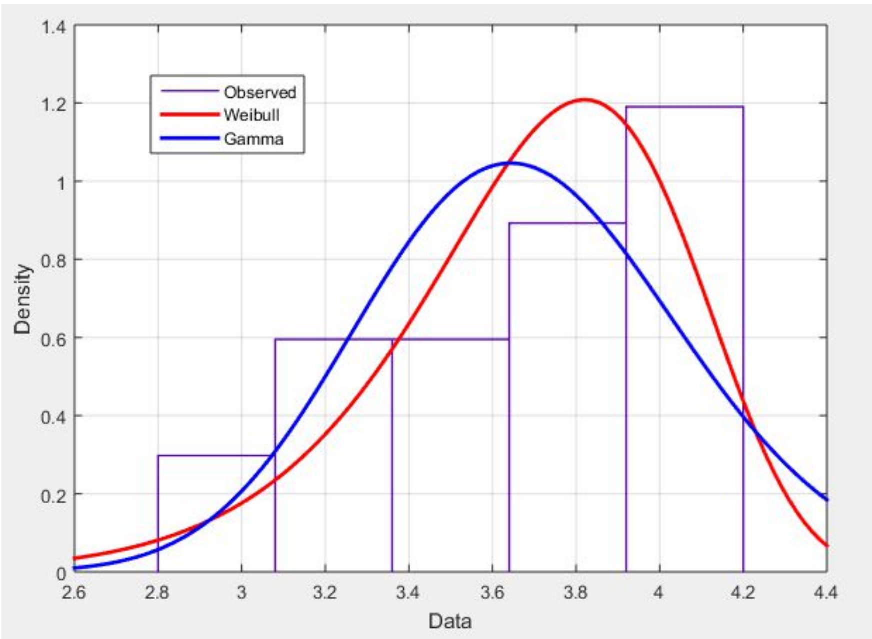


Figure 40: PDF- Ercan -2007

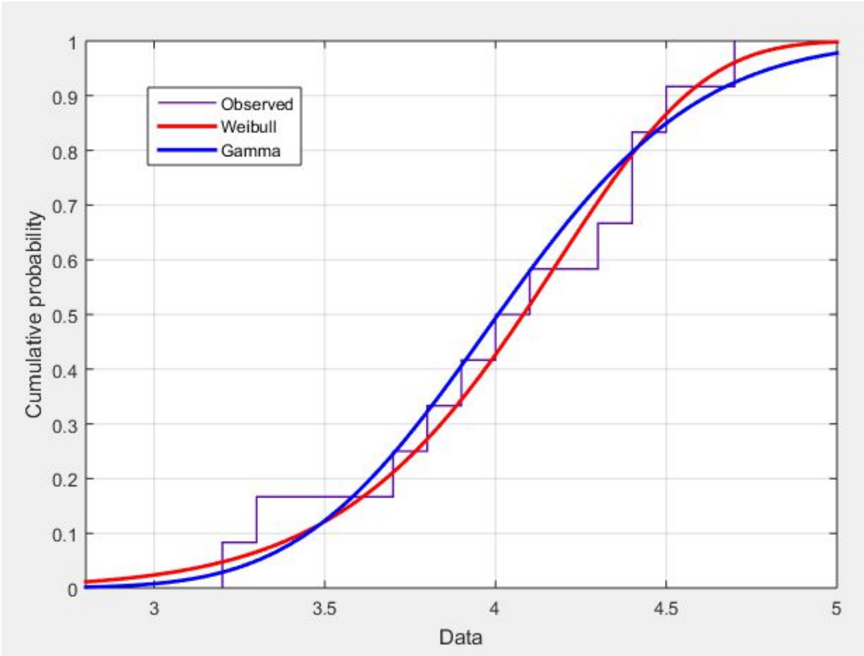


Figure 41: CDF- Ercan -2008

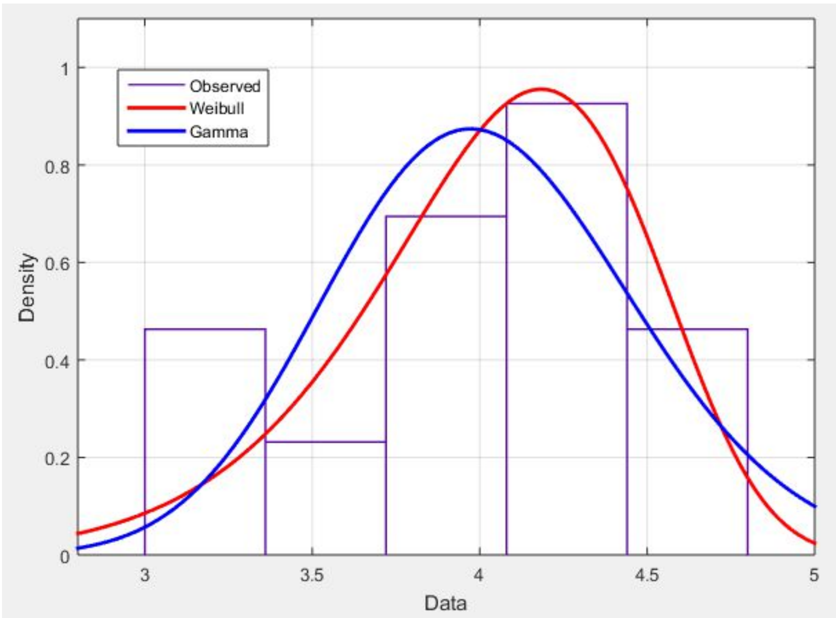


Figure 42: PDF- Ercan -2008

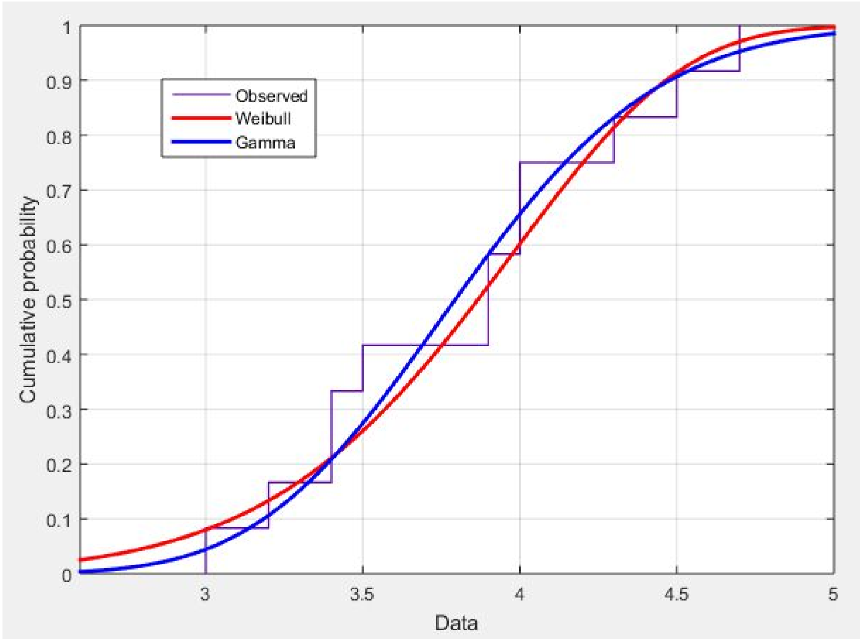


Figure 43: CDF- Ercan -2009

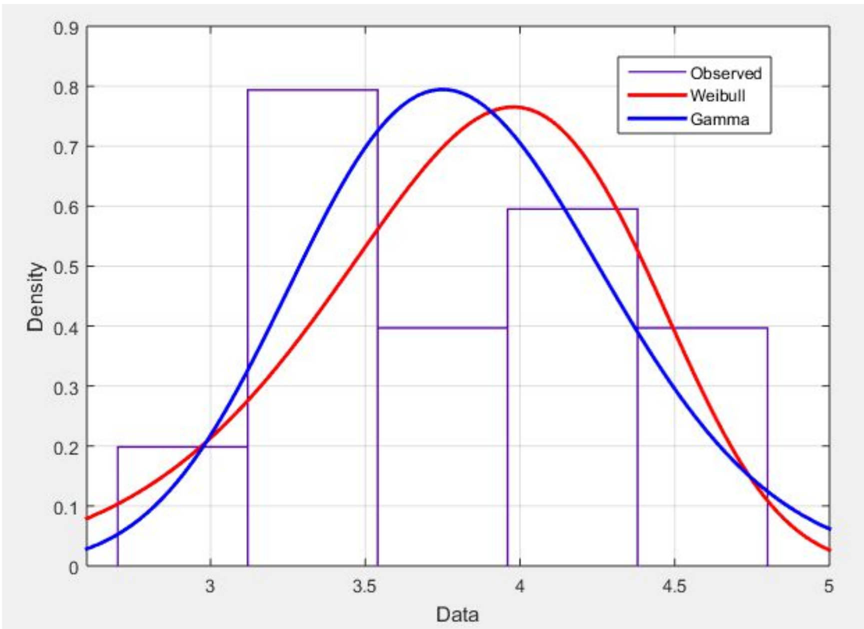


Figure 44: PDF- Ercan -2009

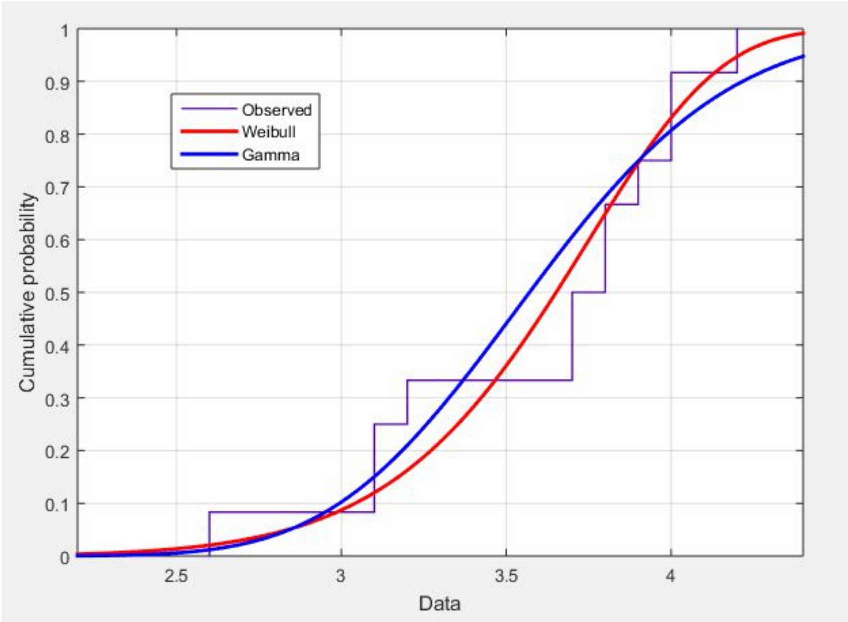


Figure 45: CDF- Ercan -2010

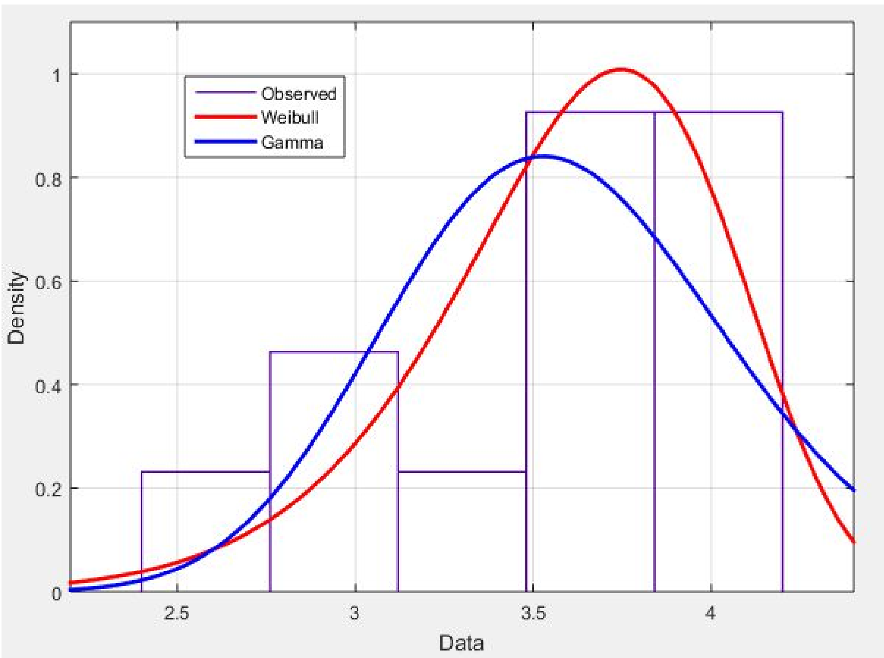


Figure 46: PDF- Ercan -2010

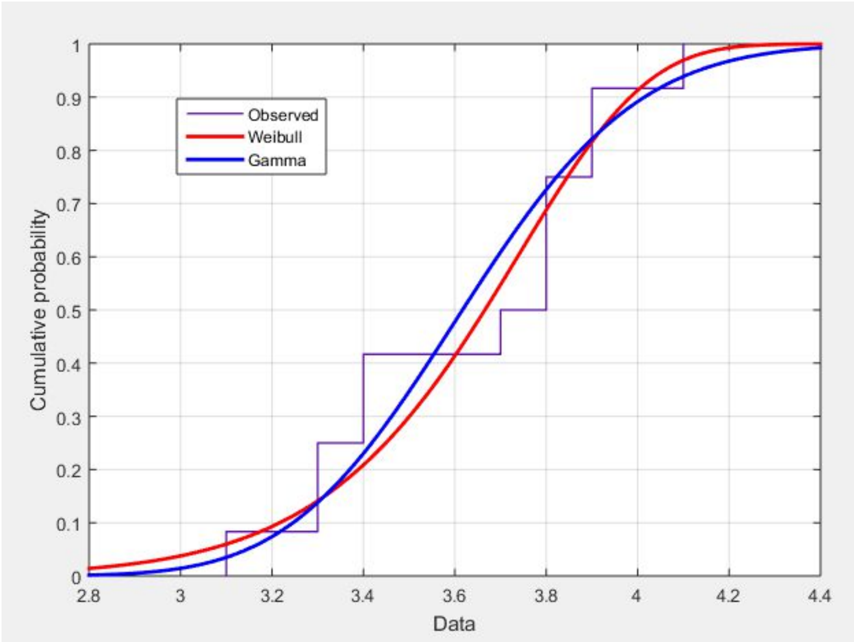


Figure 47: CDF- Ercan -2011

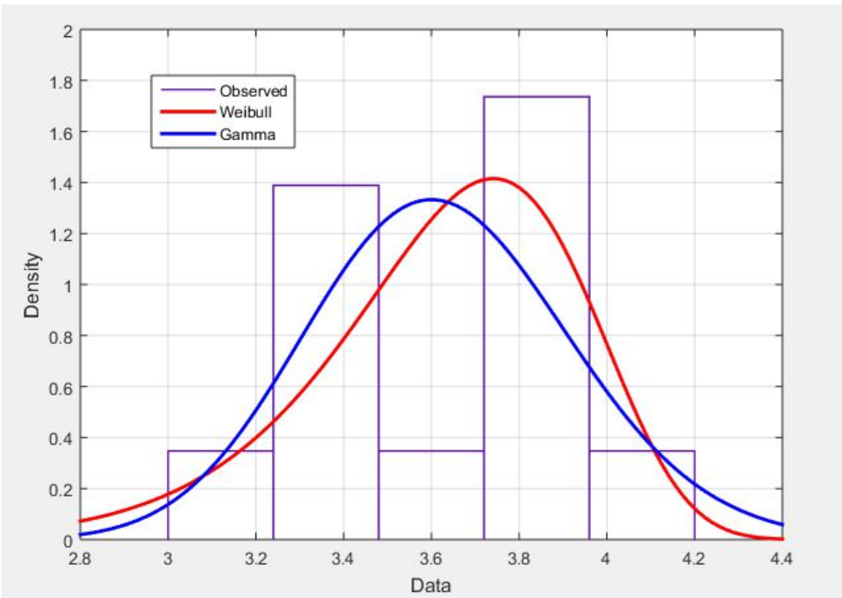


Figure 48: PDF- Ercan -2011

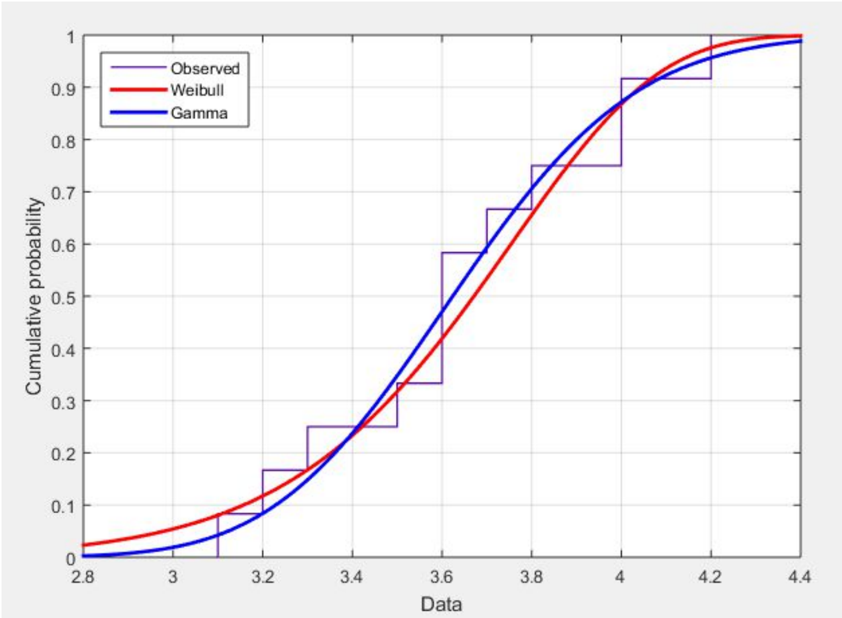
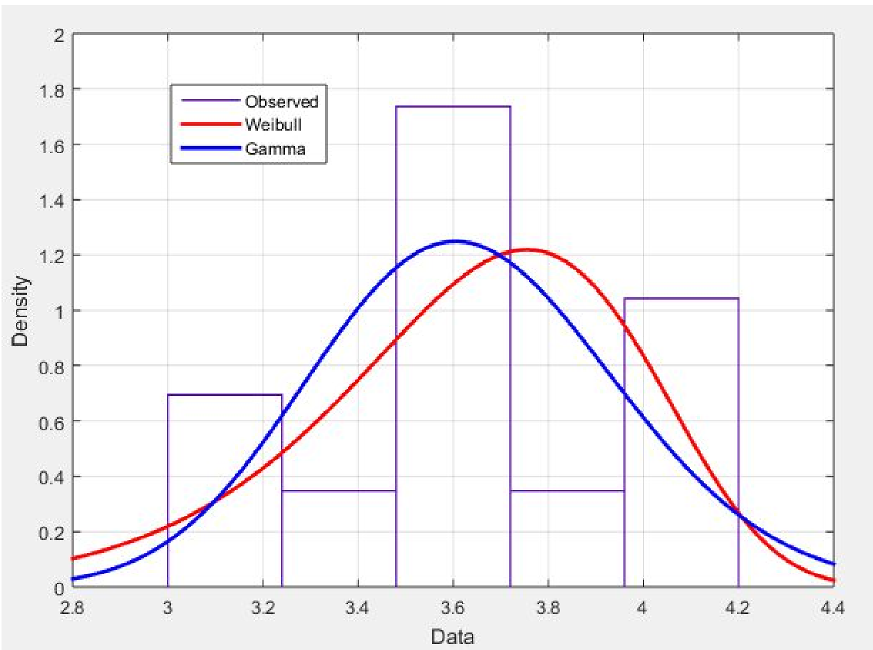


Figure 49: CDF- Ercan -2012



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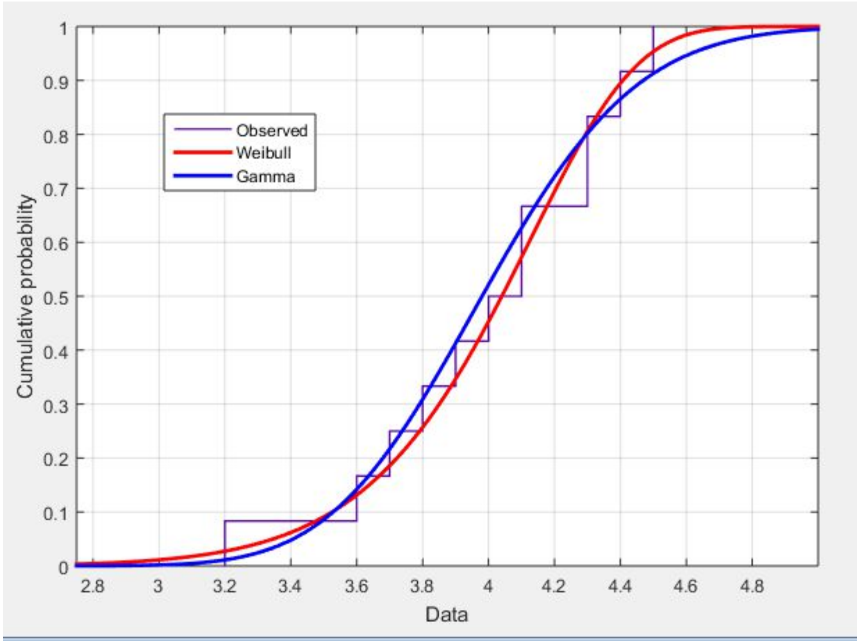

Figure 51: CDF- Ercan -2013

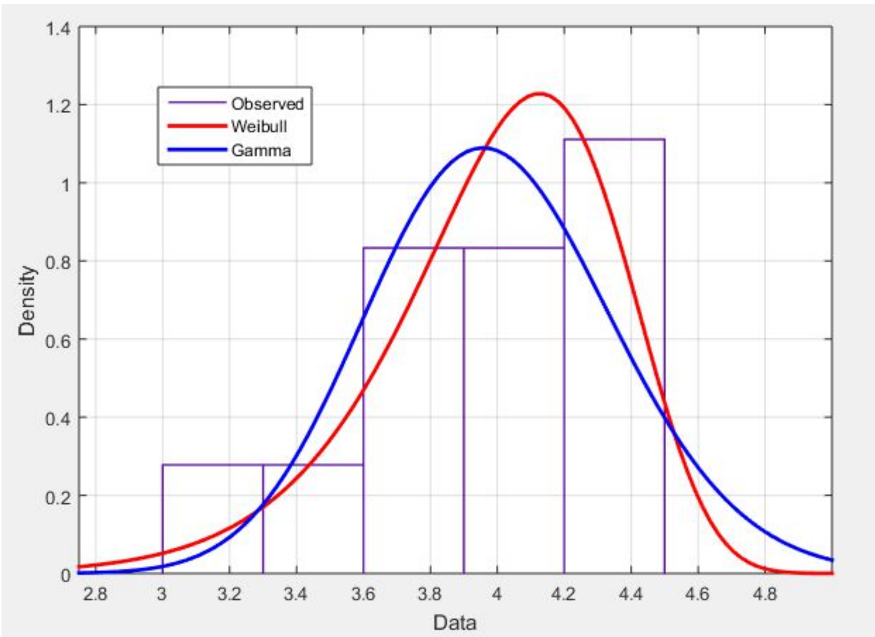

Figure 52: PDF- Ercan -2013

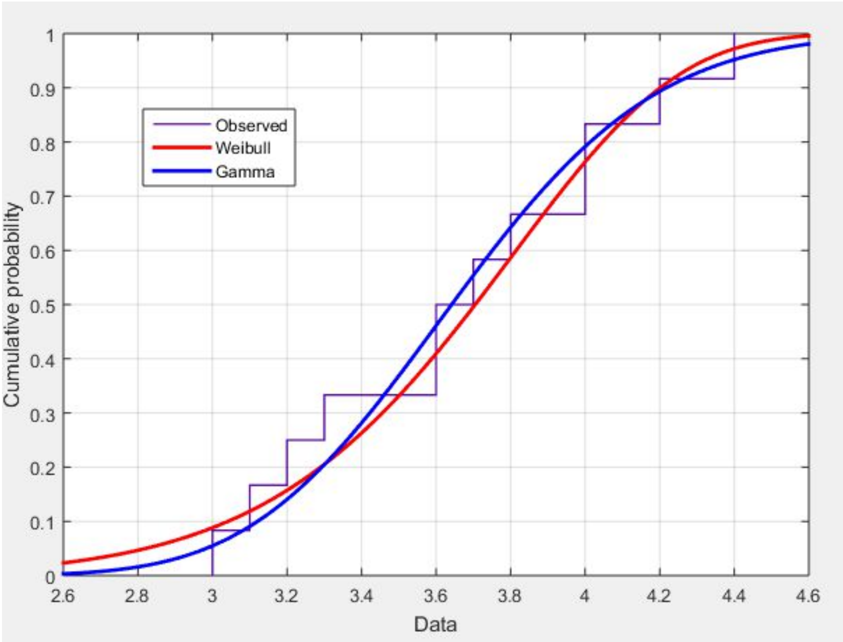

Figure 53: CDF- Ercan -2014

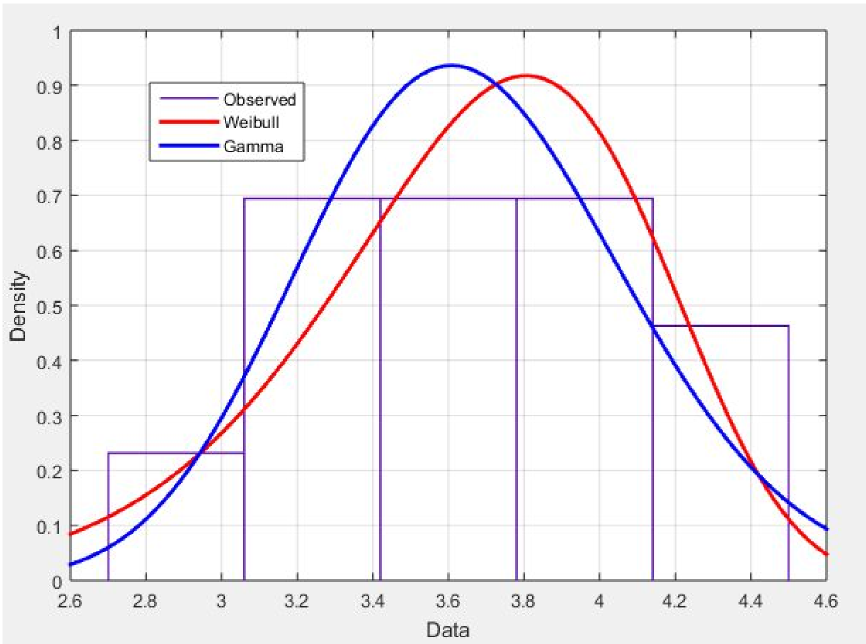

Figure 54: PDF- Ercan -2014

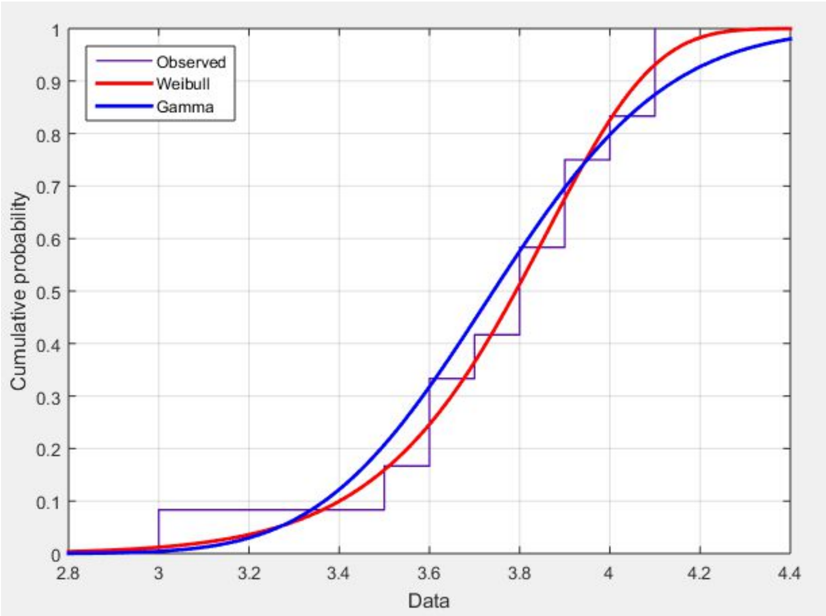

Figure 55: CDF- Ercan -2015

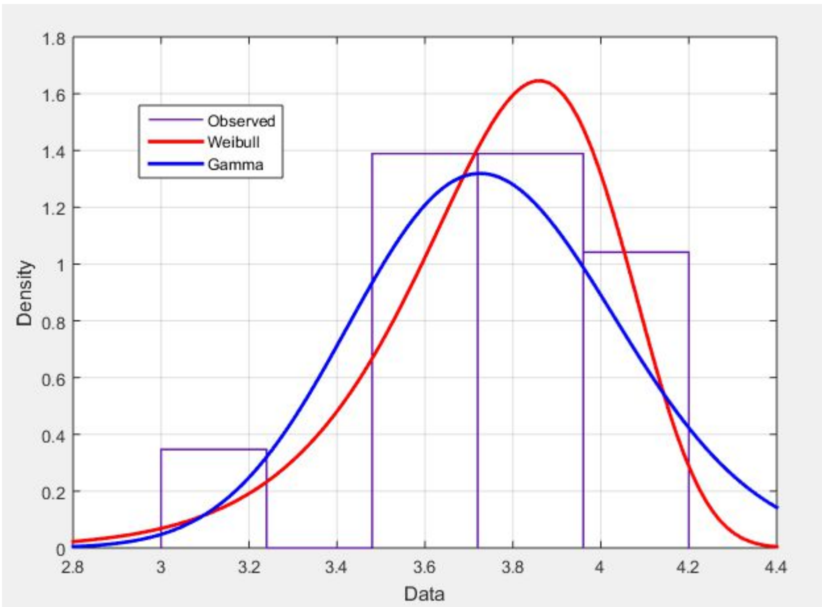

Figure 56: PDF- Ercan -2015

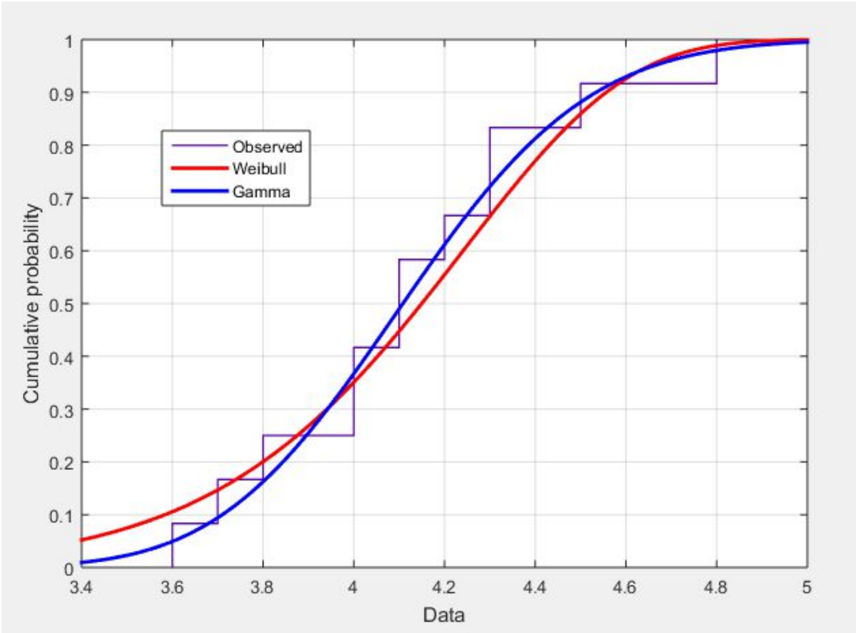

Figure 57: CDF- Ercan -2016

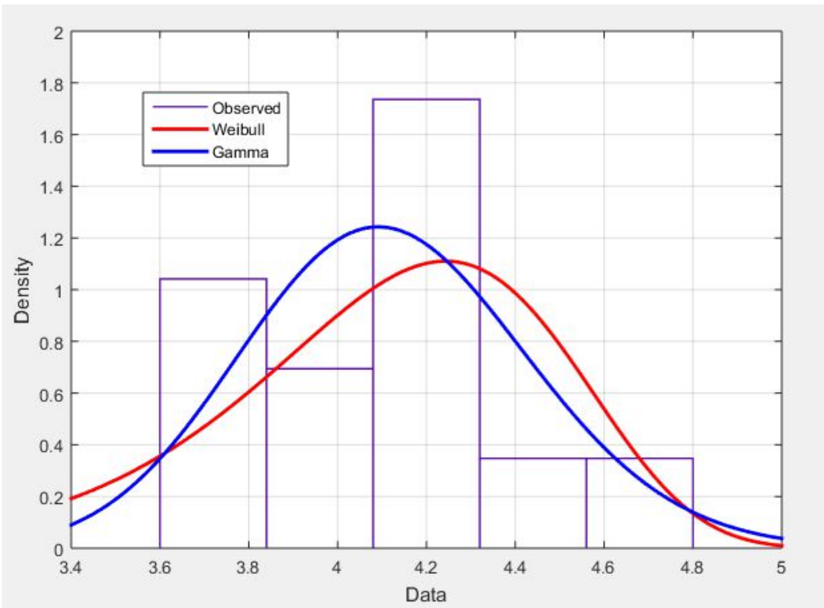

Figure 58: PDF- Ercan -2016

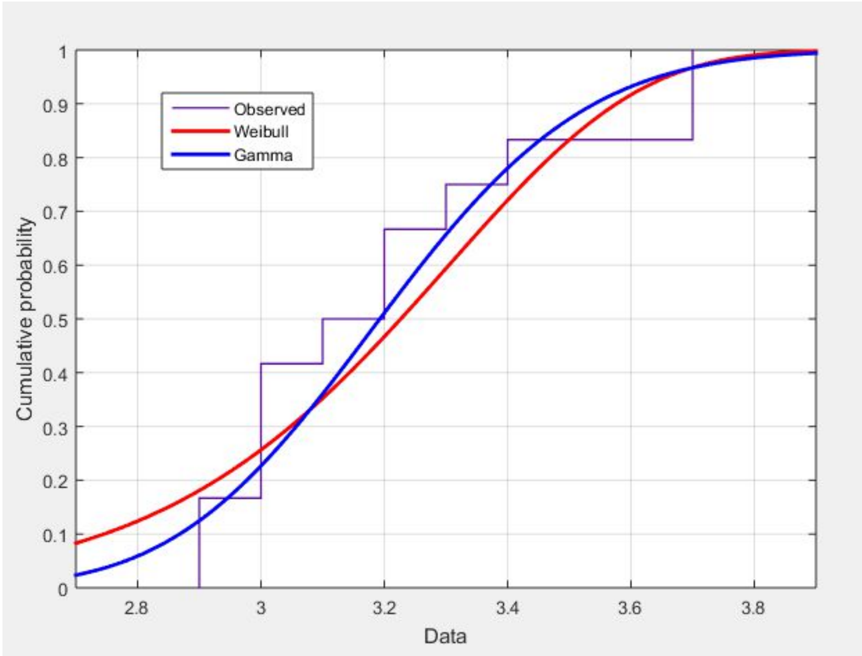

Figure 59: CDF-Gazimağusa-2000

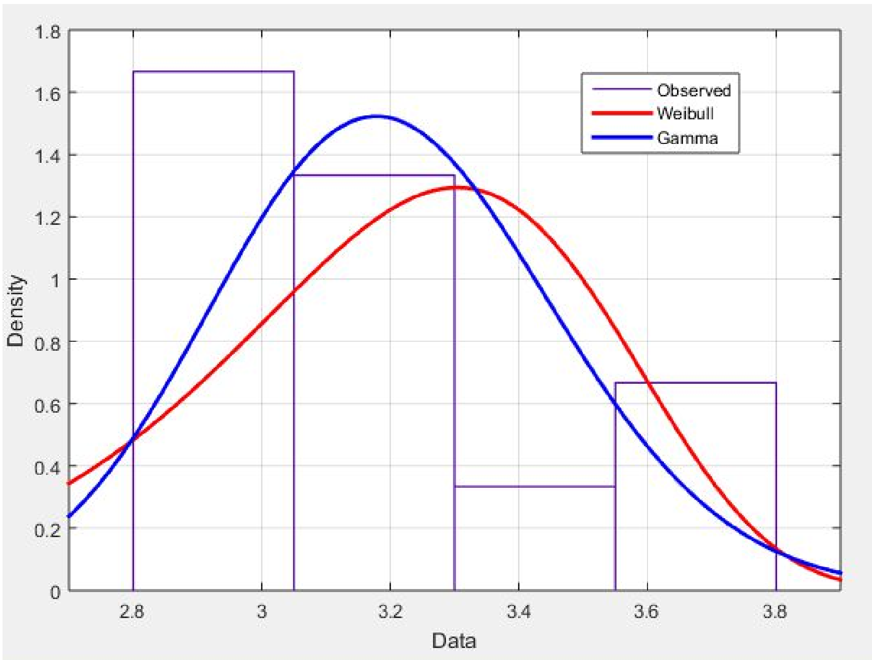

Figure 60: PDF- Gazimağusa -2000

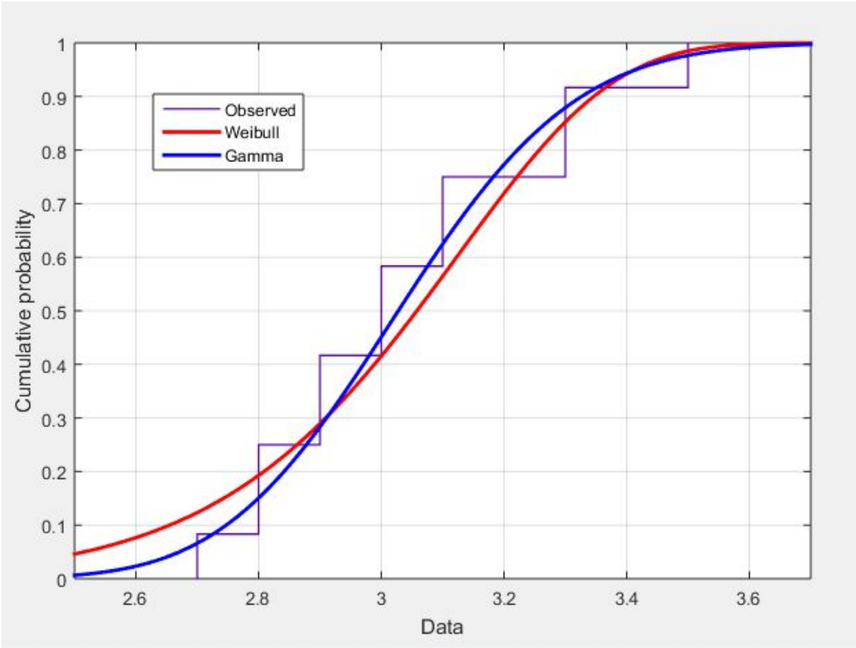

Figure 61: CDF- Gazimağusa -2001

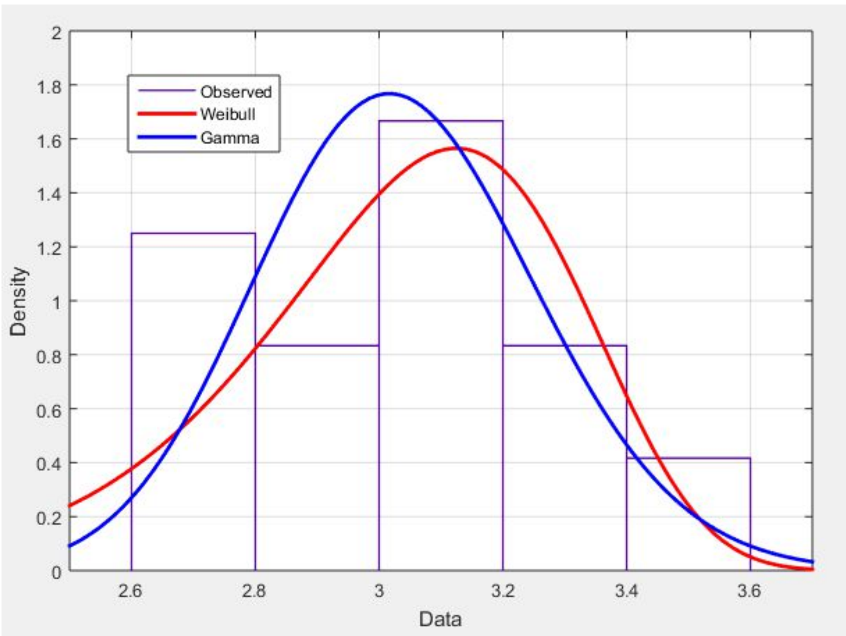

Figure 62: PDF- Gazimağusa -2001

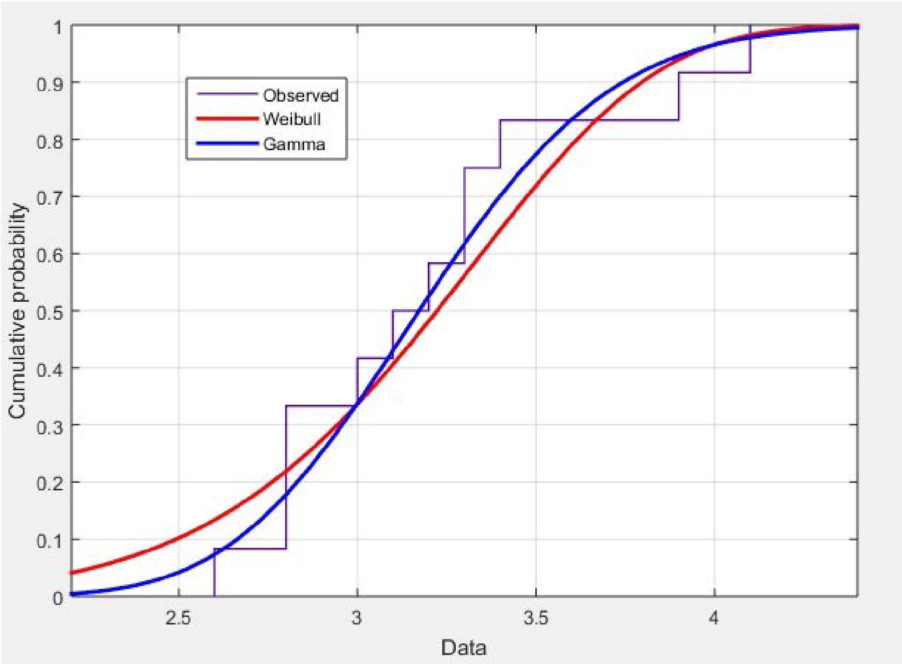

Figure 63: CDF- Gazimağusa -2002

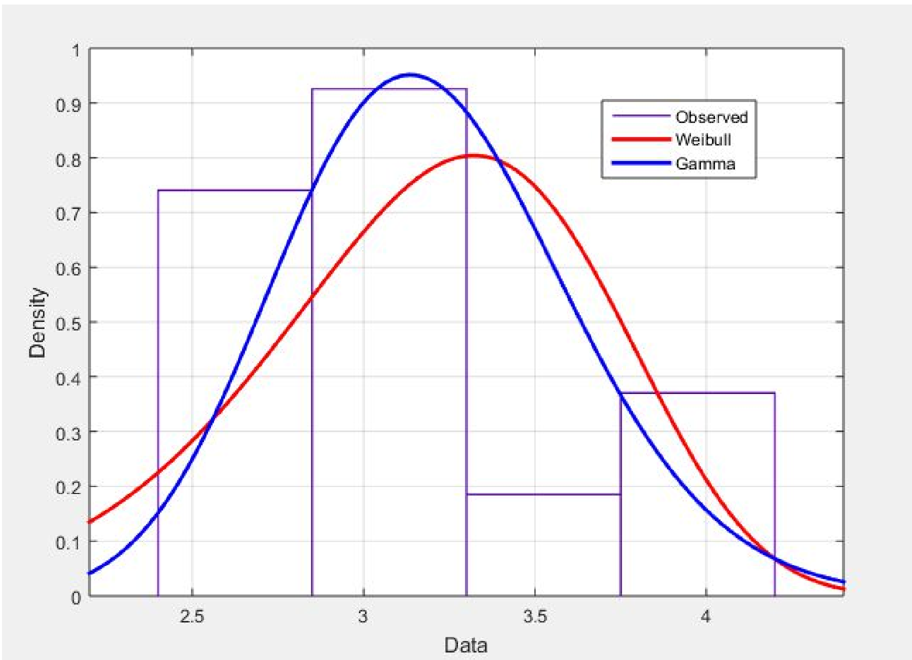

Figure 64: PDF- Gazimağusa -2002

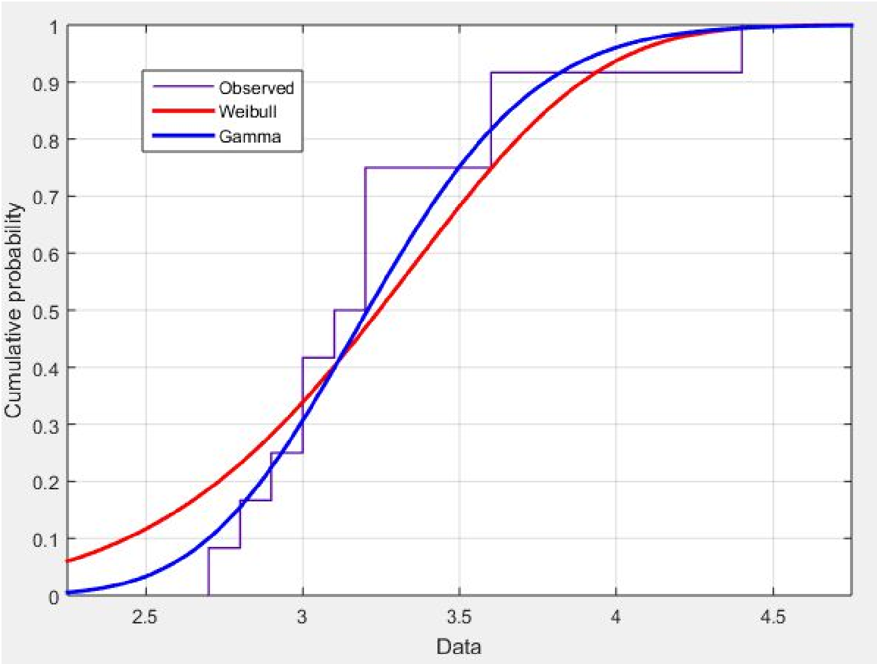

Figure 65: CDF- Gazimağusa -2003

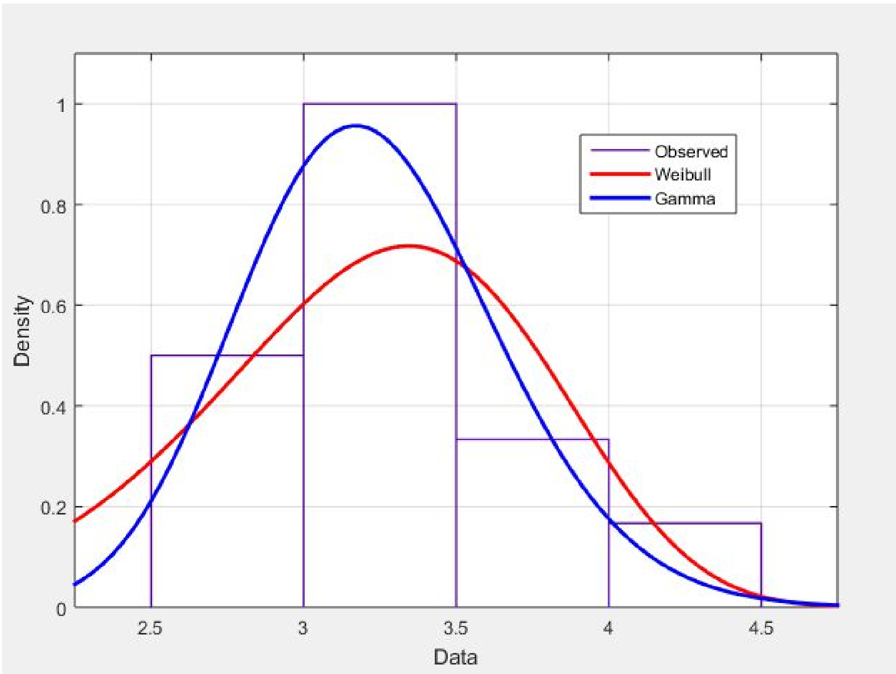

Figure 66: PDF- Gazimağusa -2003

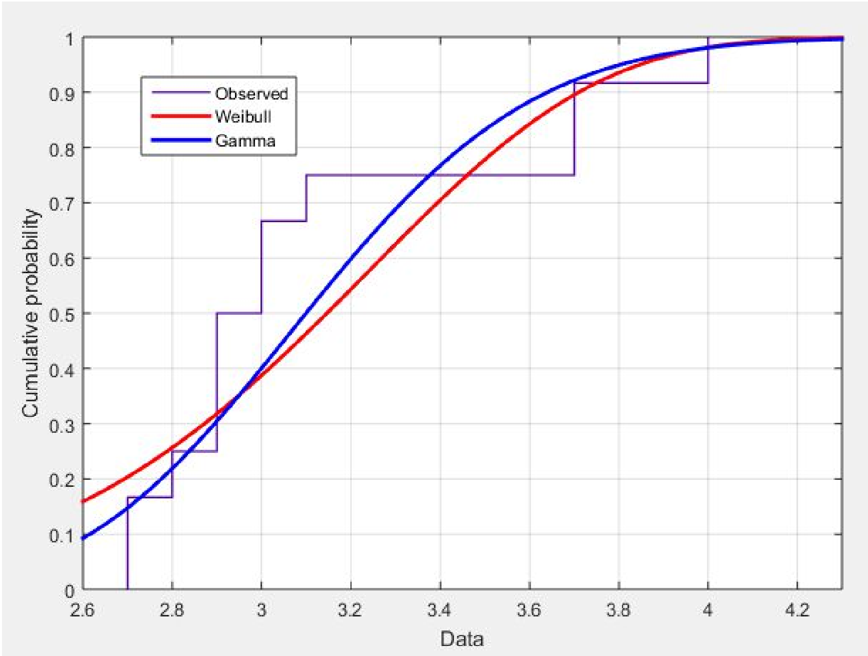

Figure 67: CDF- Gazimağusa -2004

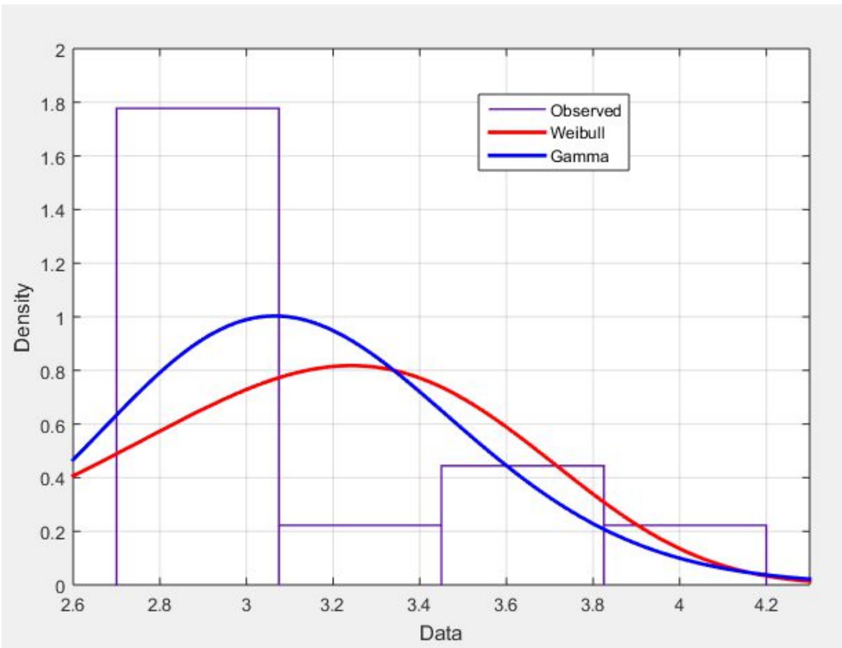

Figure 68: PDF- Gazimağusa -2004

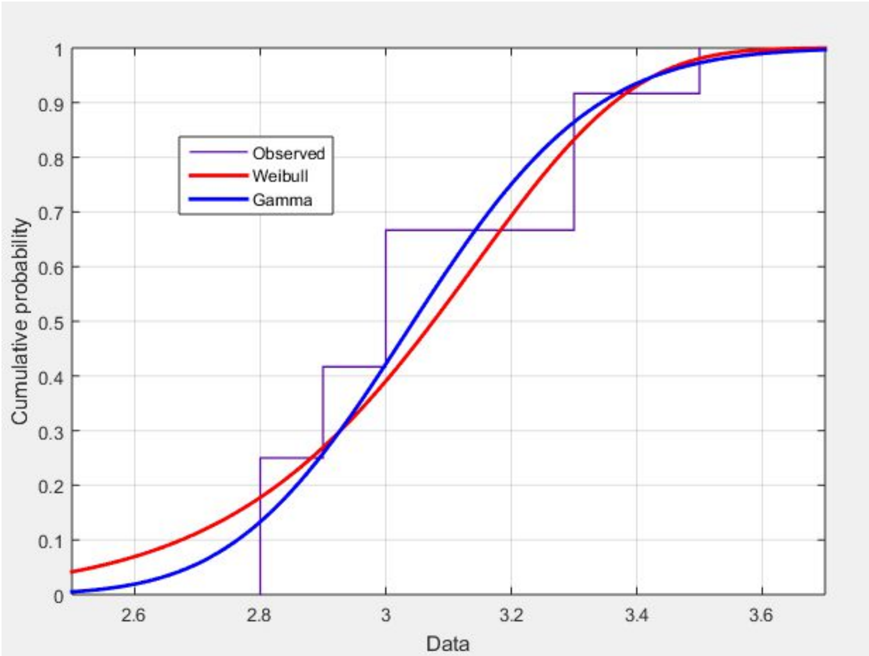

Figure 69: CDF- Gazimağusa -2005

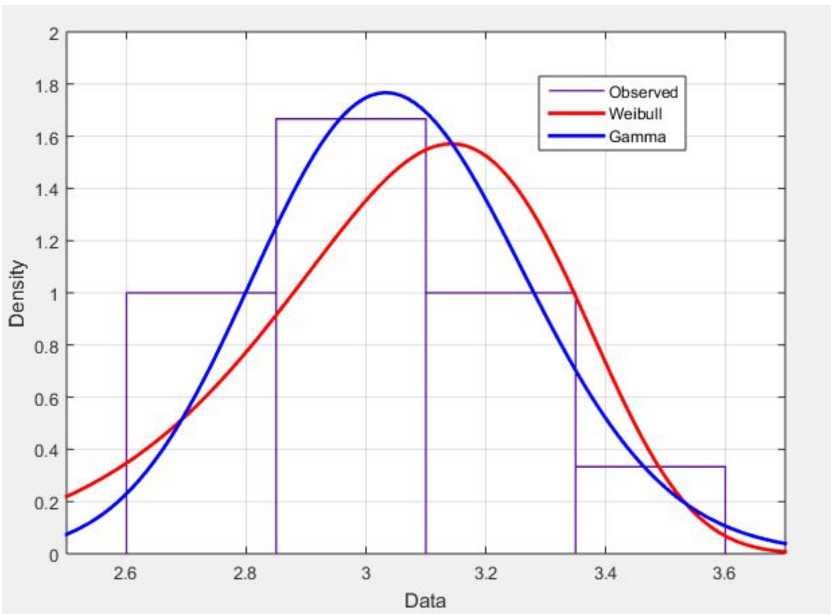

Figure 70: PDF- Gazimağusa -2005

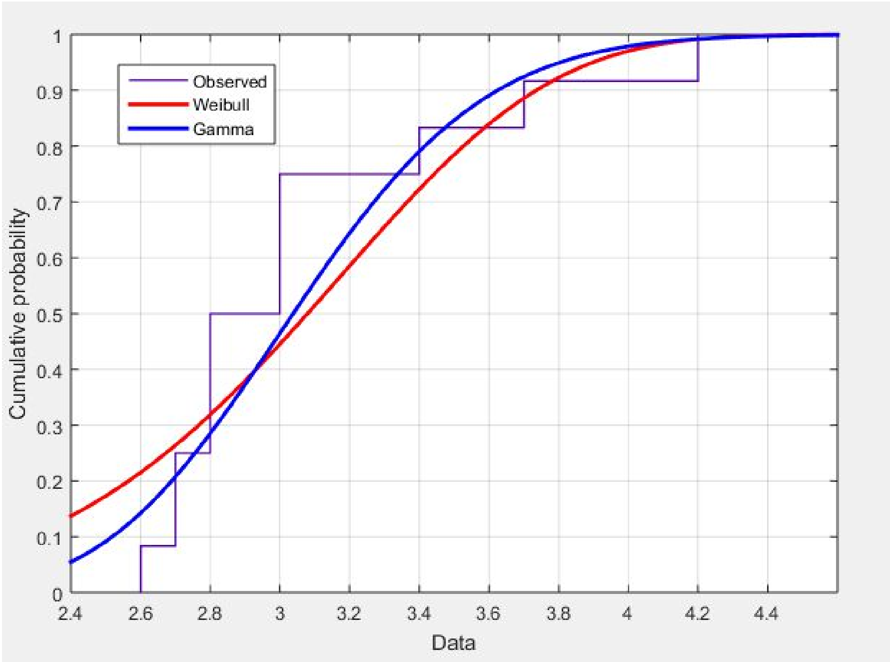

Figure 71: CDF- Gazimağusa -2006

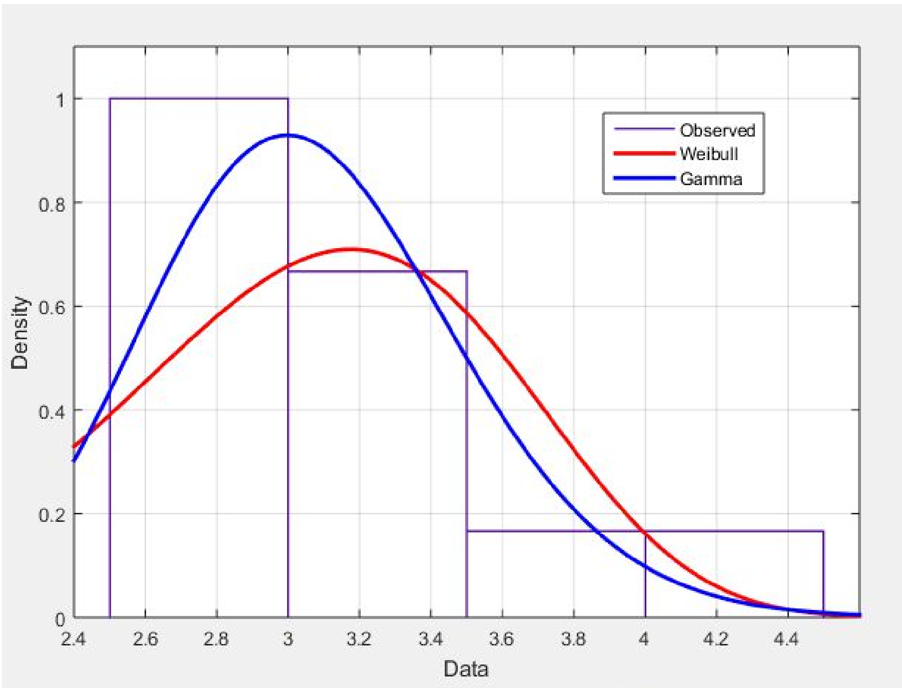

Figure 72: PDF- Gazimağusa -2006

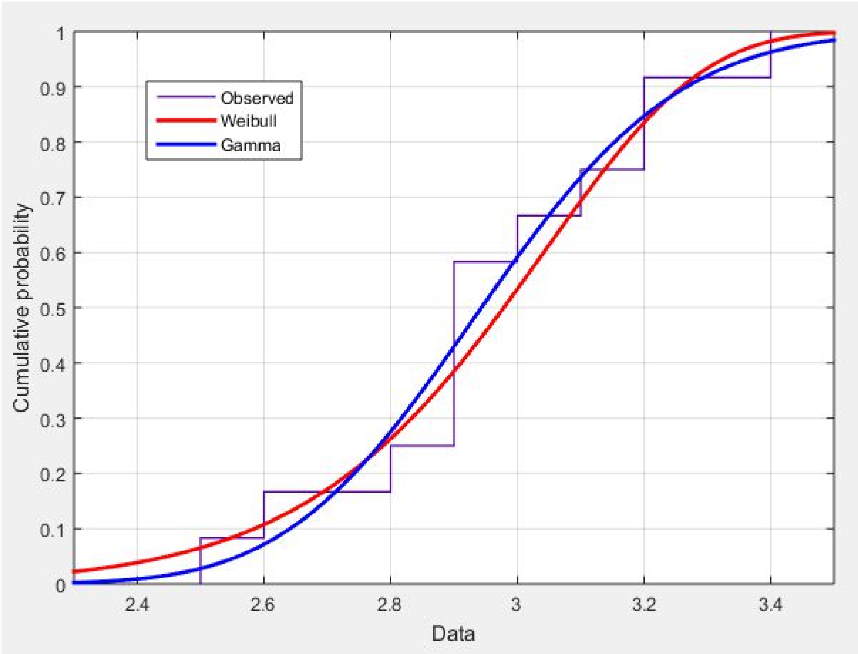

Figure 73: CDF- Gazimağusa -2007

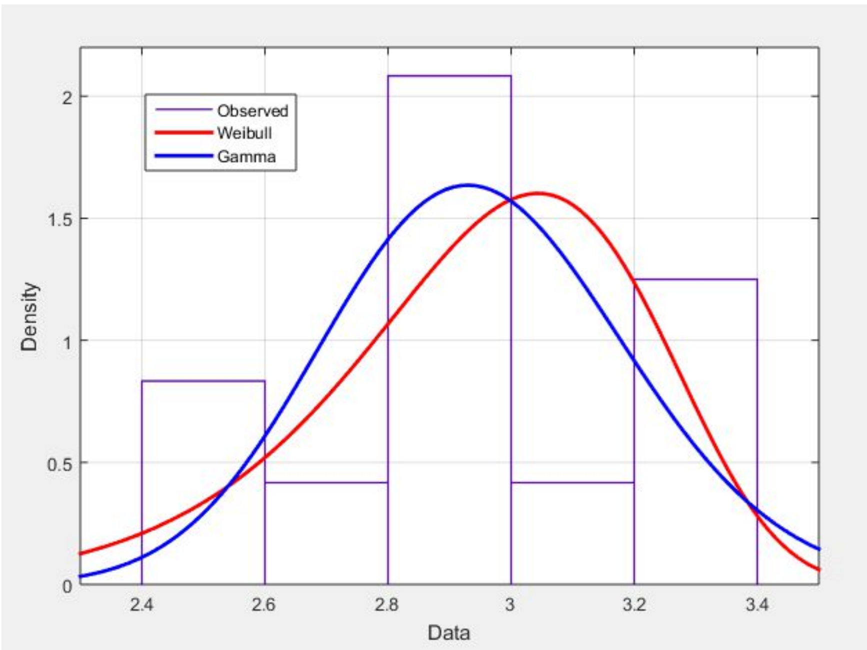

Figure 74: PDF- Gazimağusa -2007

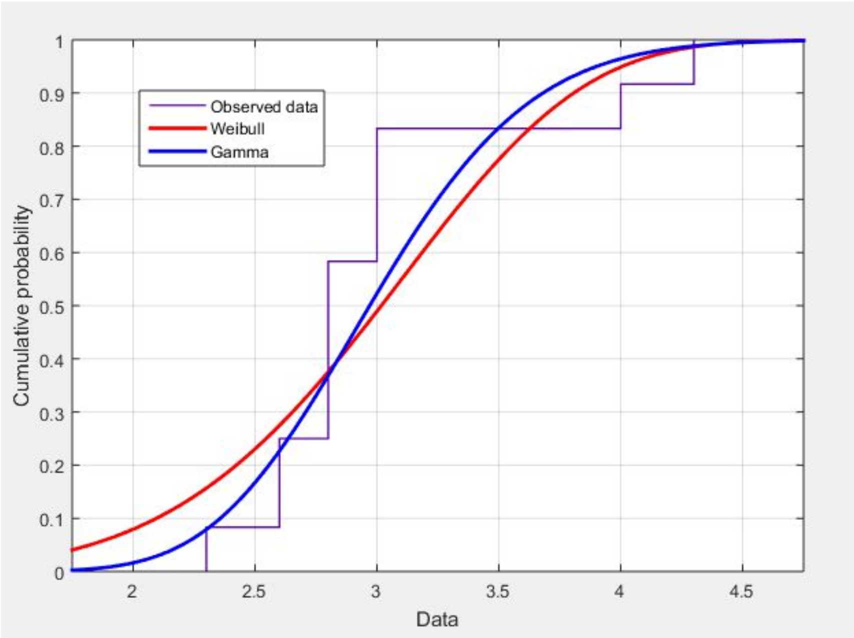

Figure 75: CDF- Gazimağusa -2008

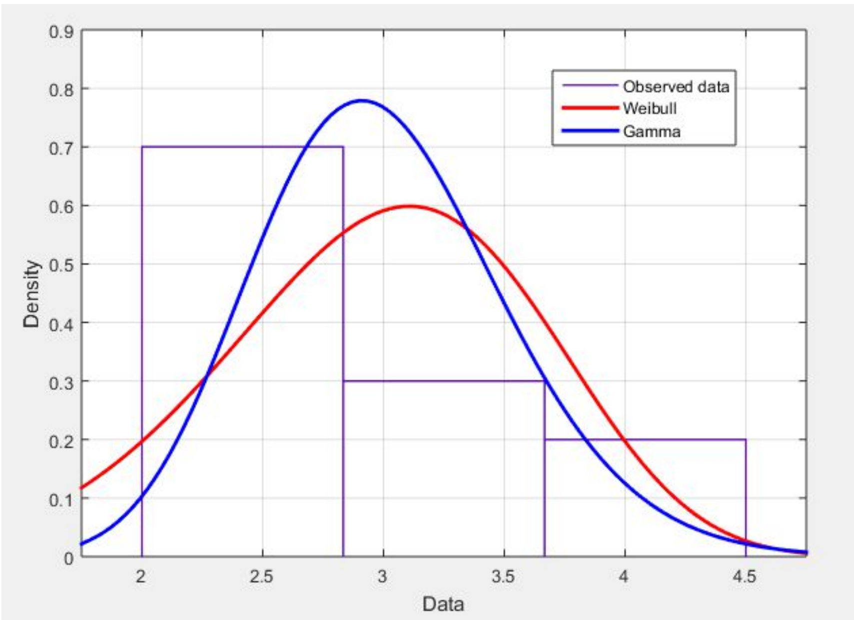

Figure 76: PDF- Gazimağusa -2008

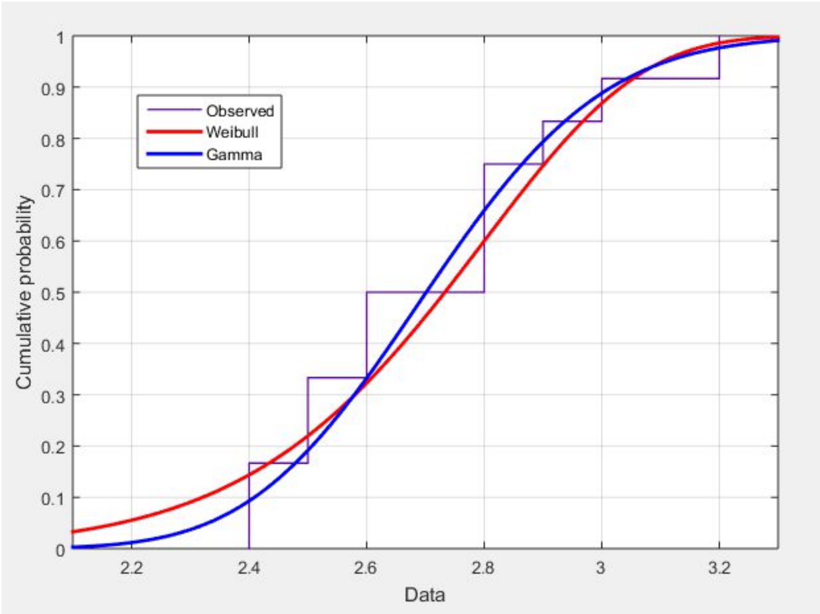

Figure 77: CDF- Gazimağusa -2009

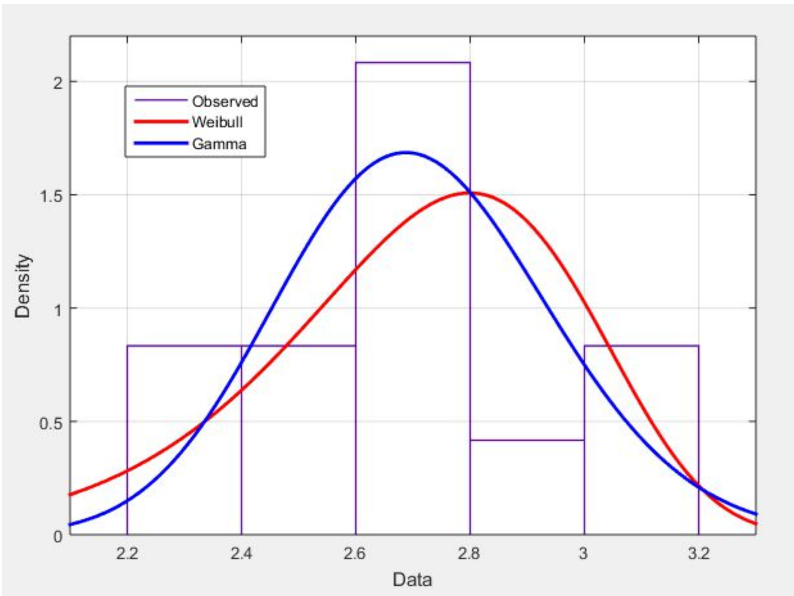

Figure 78: PDF- Gazimağusa -2009

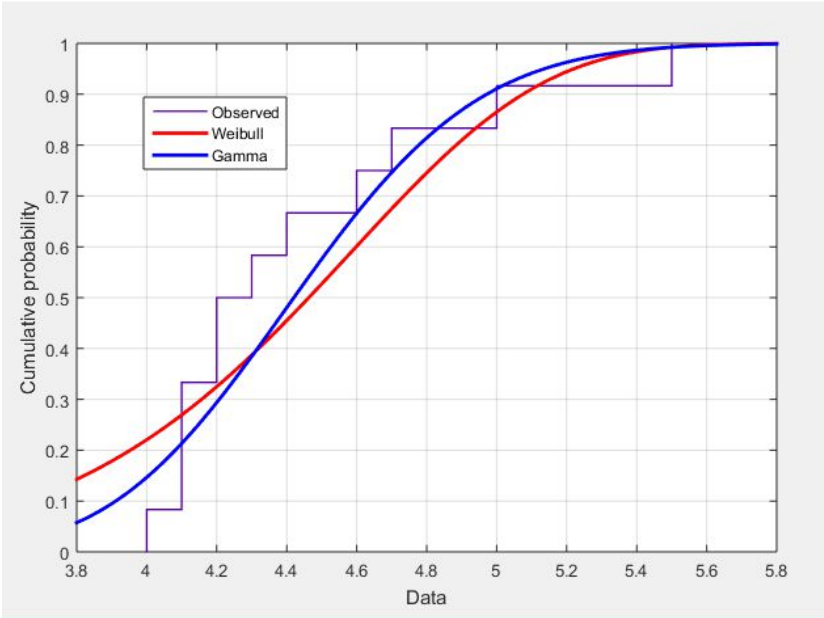

Figure 79: CDF- Gazimağusa -2010

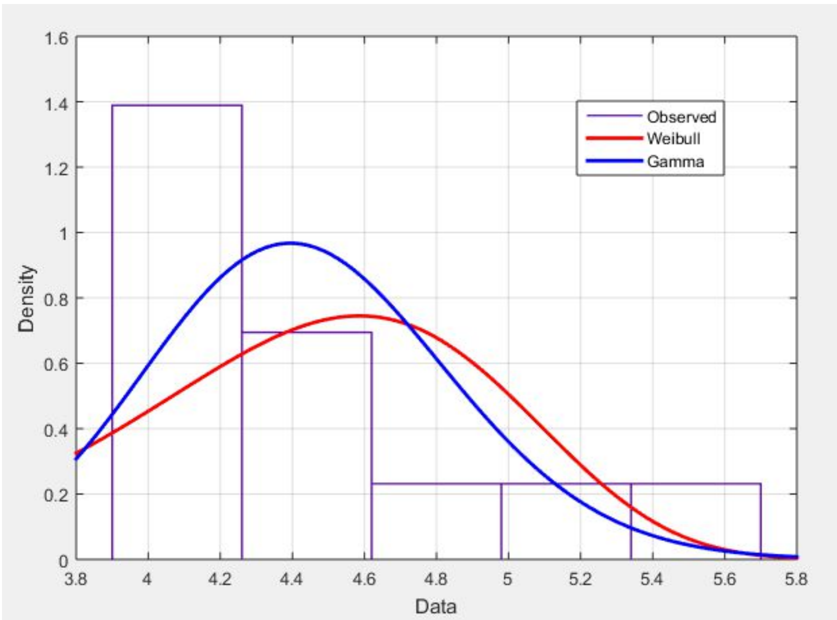

Figure 80: PDF- Gazimağusa -2010

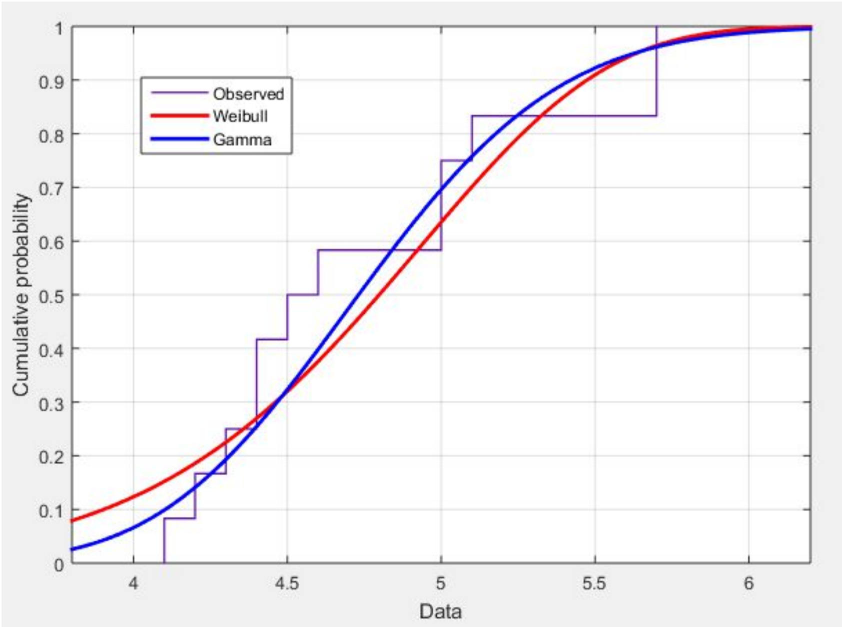

Figure 81: CDF- Gazimağusa -2011

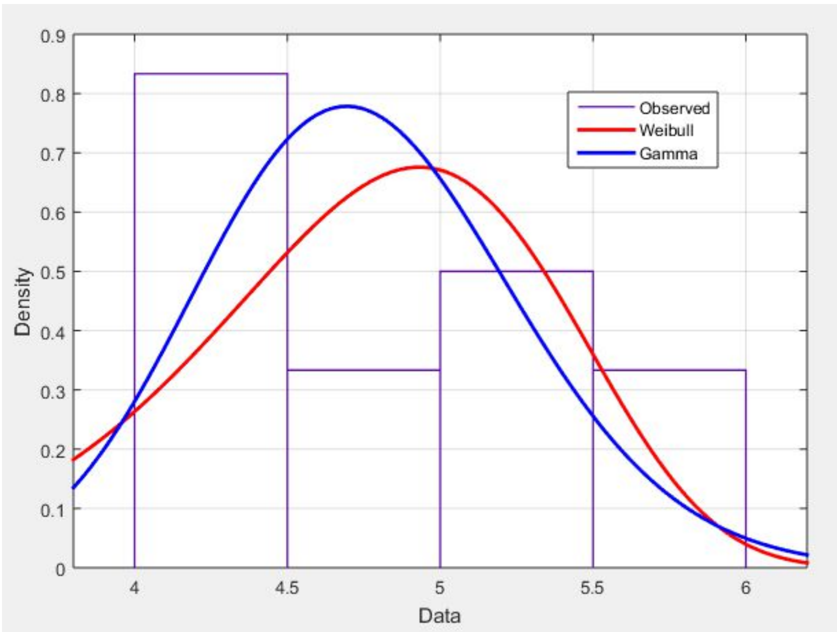

Figure 82: PDF- Gazimağusa -2011

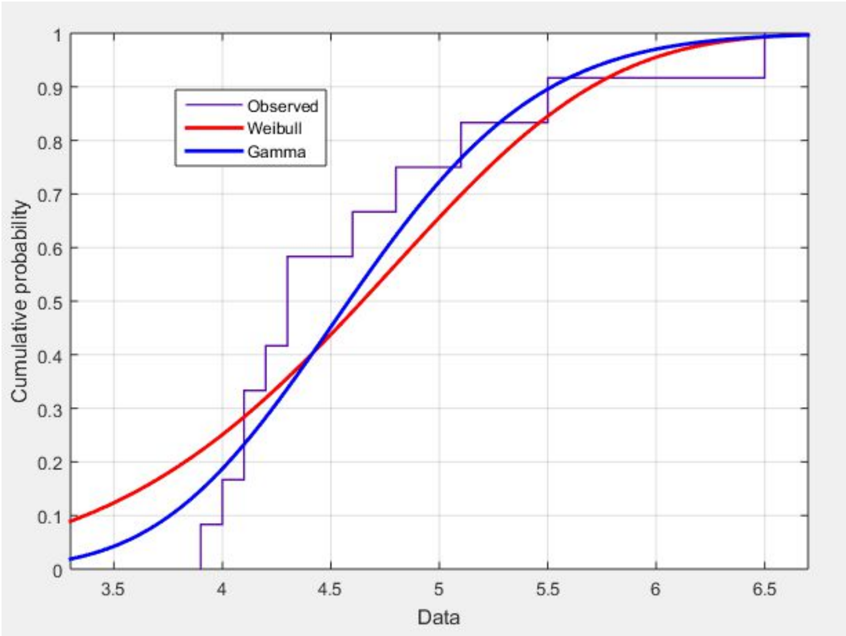

Figure 83: CDF- Gazimağusa -2012

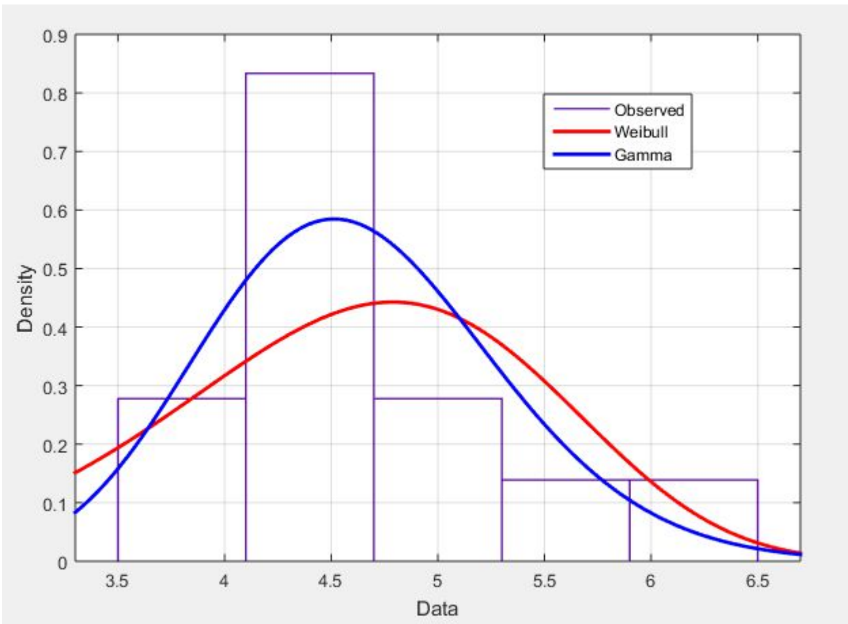

Figure 84: PDF- Gazimağusa -2012

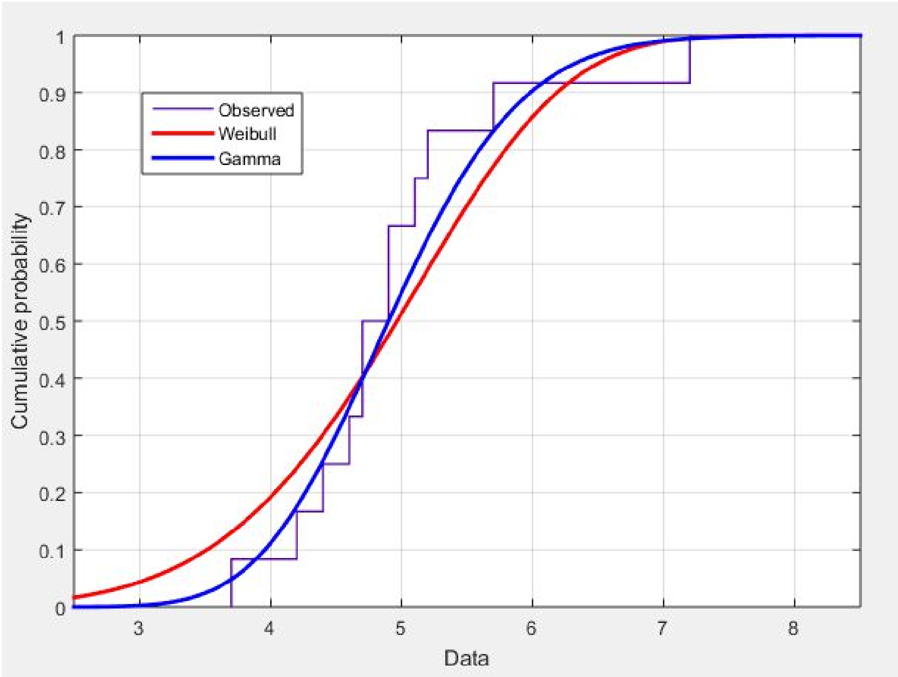

Figure 85: CDF- Gazimağusa -2013

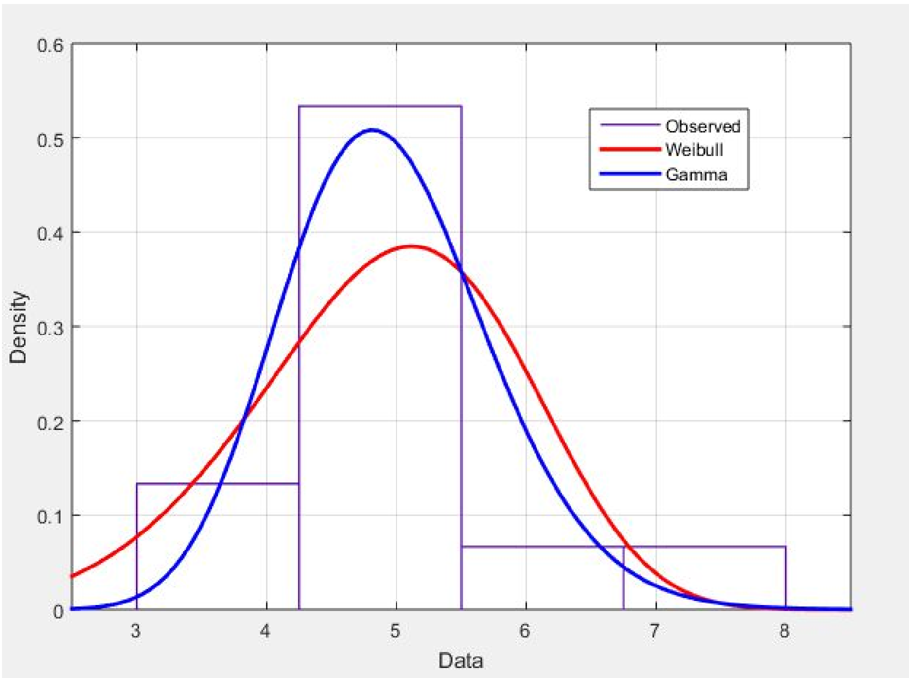

Figure 86: PDF- Gazimağusa -2013

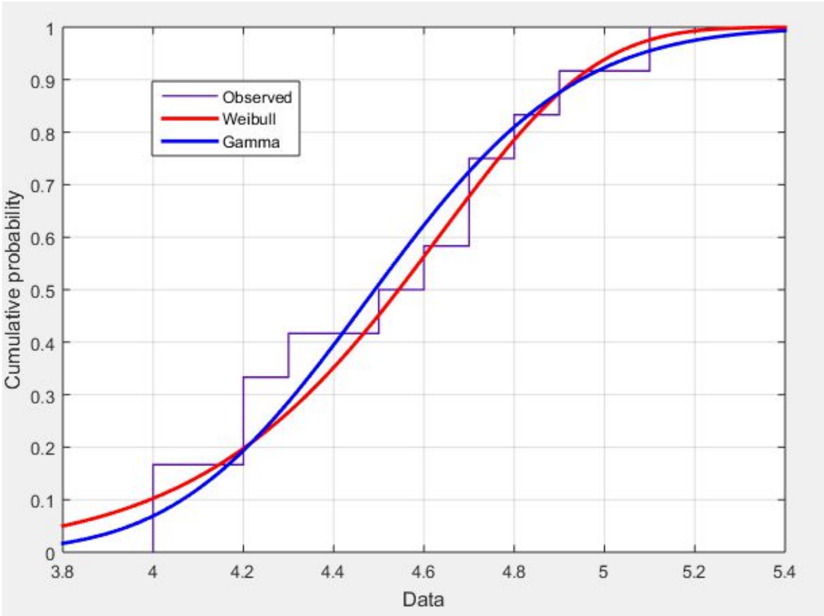

Figure 87: CDF- Gazimağusa -2014

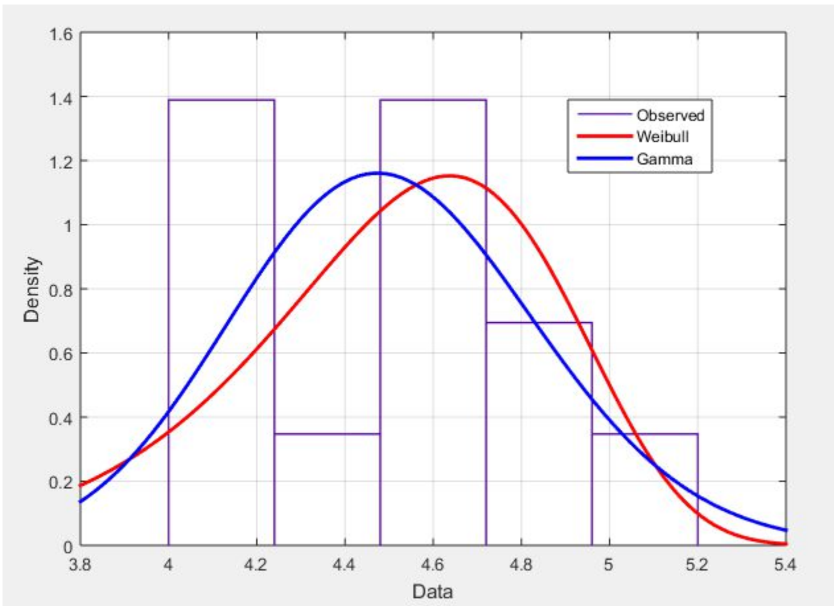

Figure 88: PDF- Gazimağusa -2014

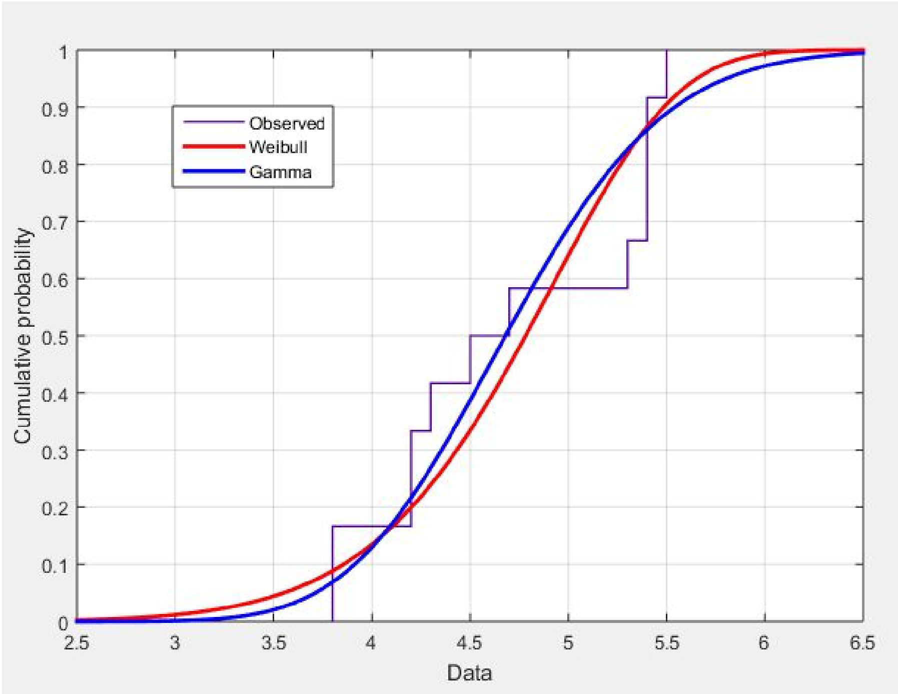

Figure 89: CDF- Gazimağusa -2015

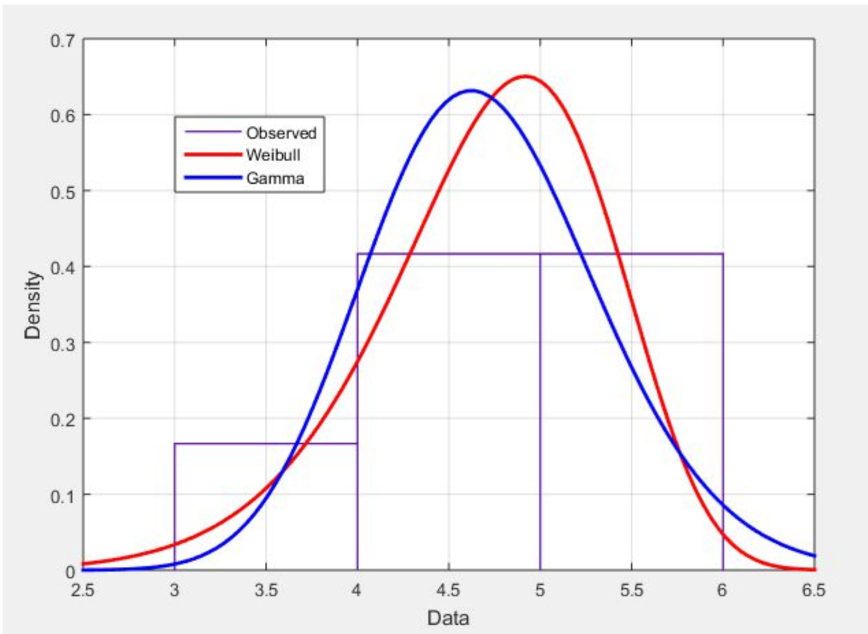

Figure 90: PDF- Gazimağusa -2015

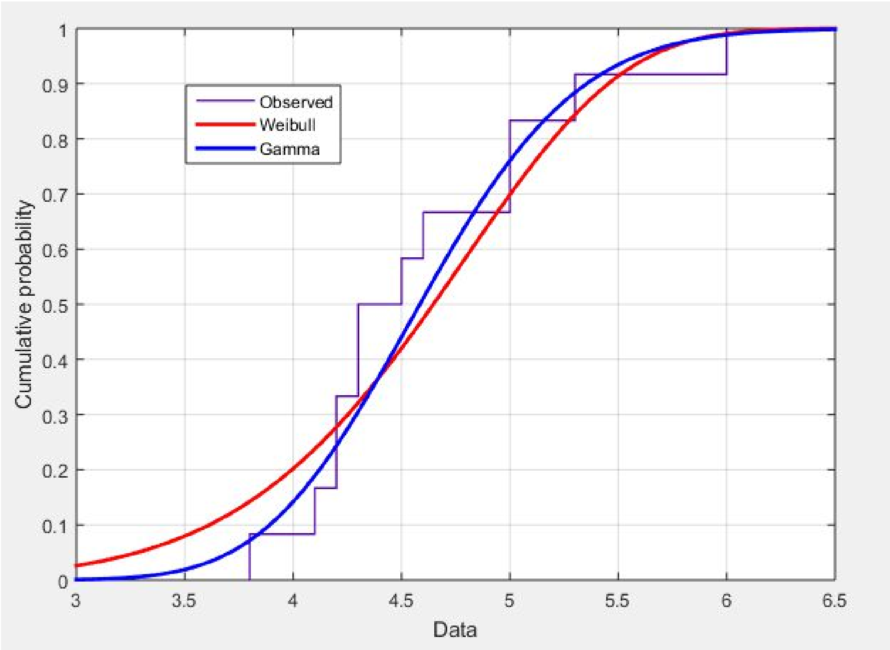

Figure 91: CDF- Gazimağusa -2016

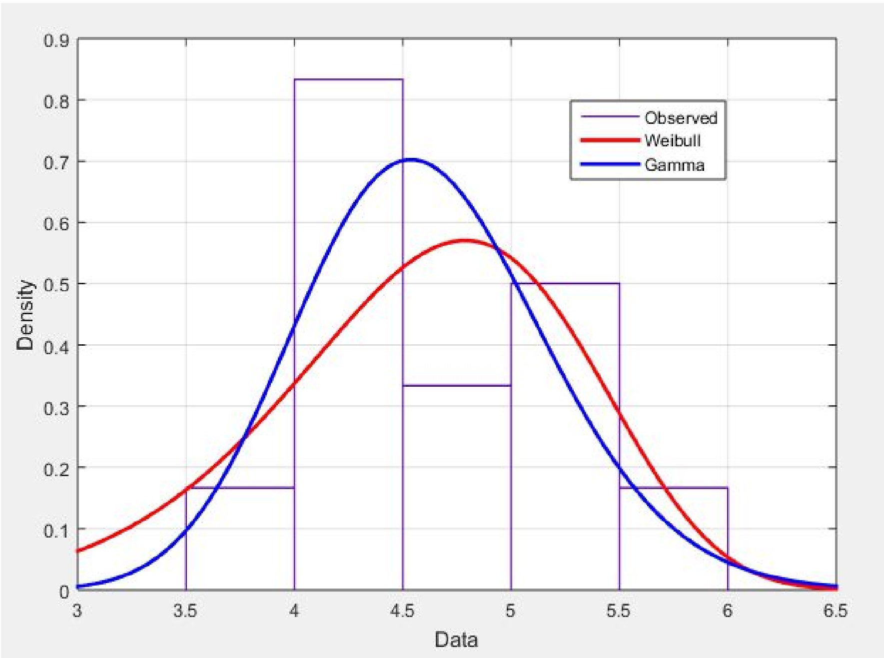

Figure 92: PDF- Gazimağusa -2016

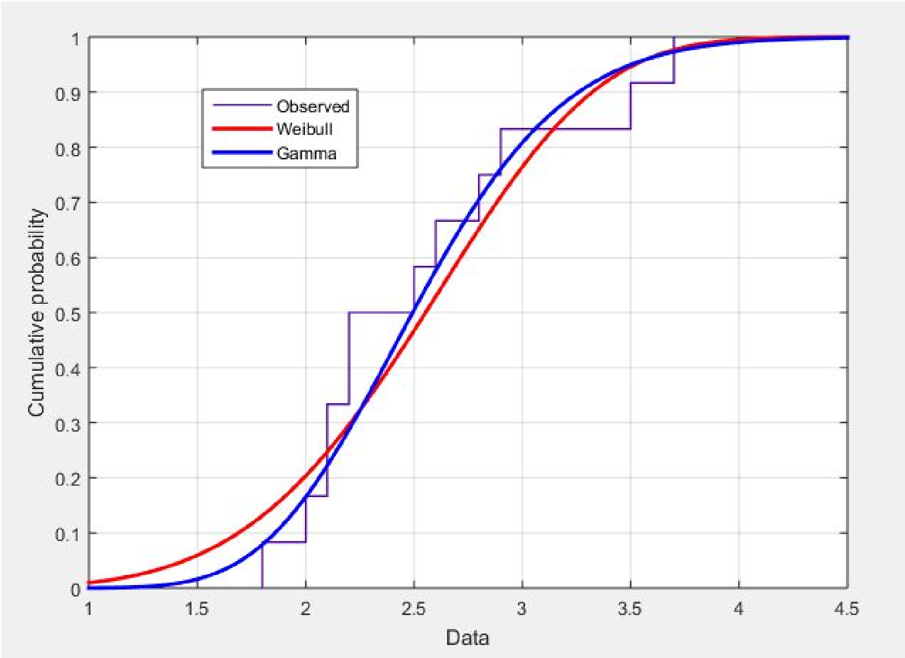

Figure 93: CDF-Girne-2000

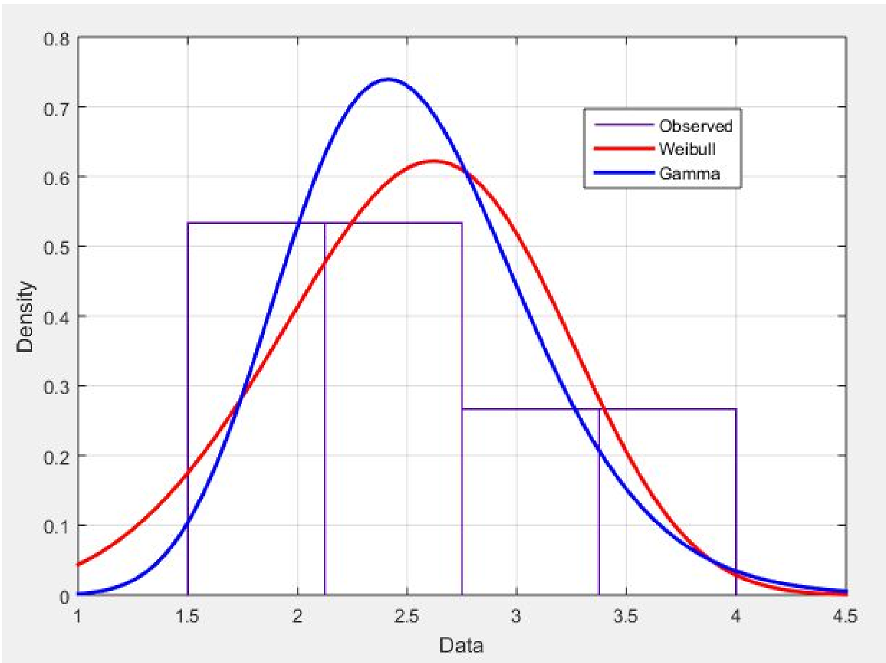

Figure 94: PDF- Girne -2000

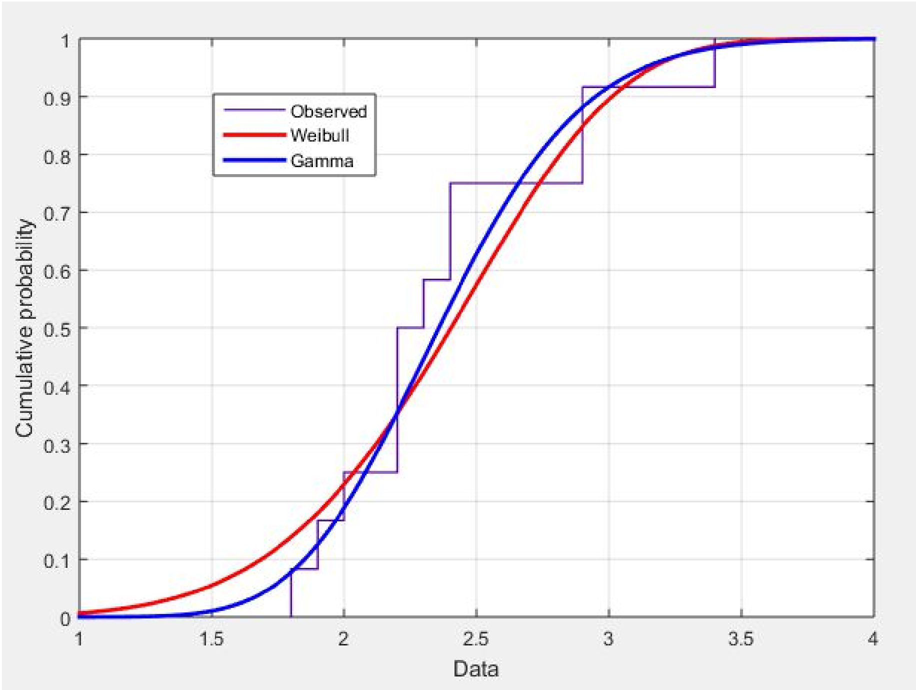

Figure 95: CDF- Girne -2001

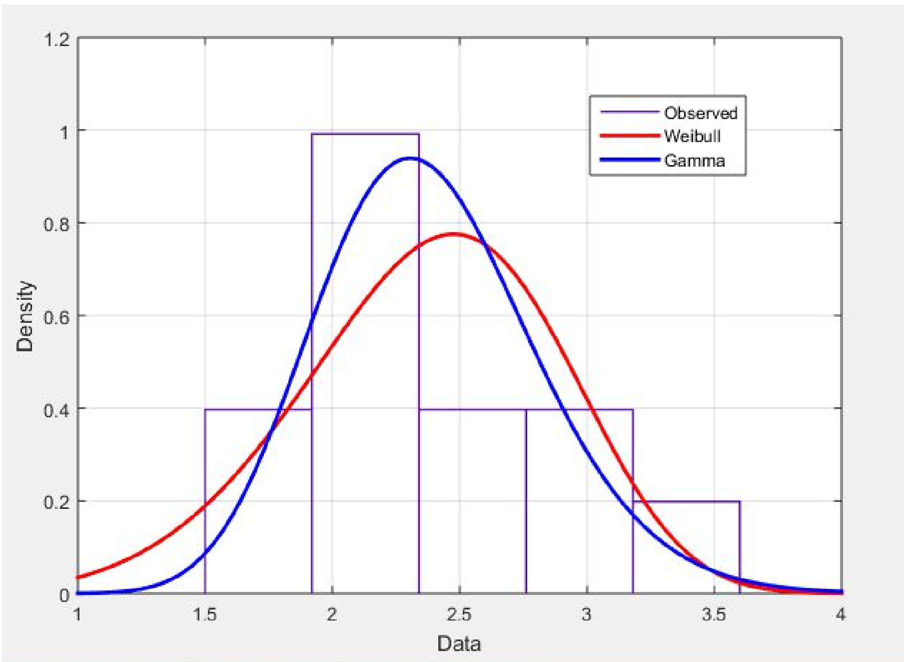

Figure 96: PDF- Girne -2001

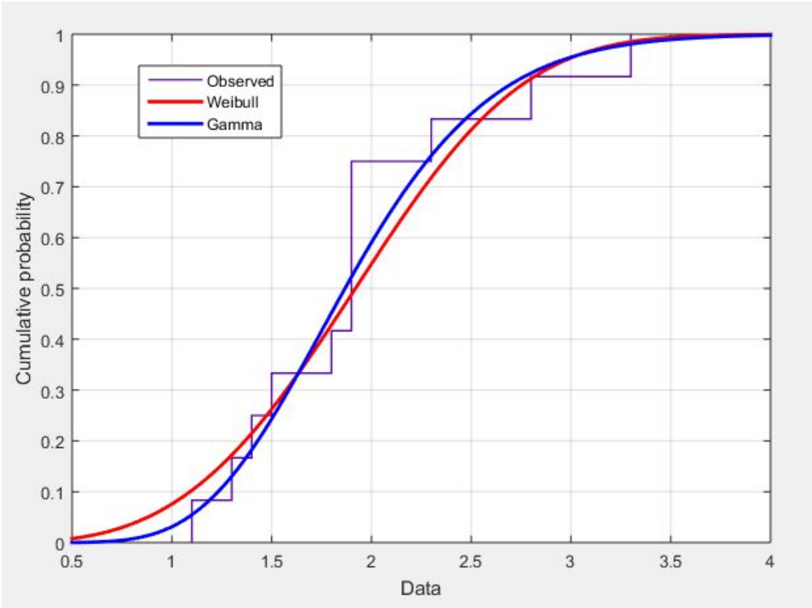

Figure 97: CDF- Girne -2002

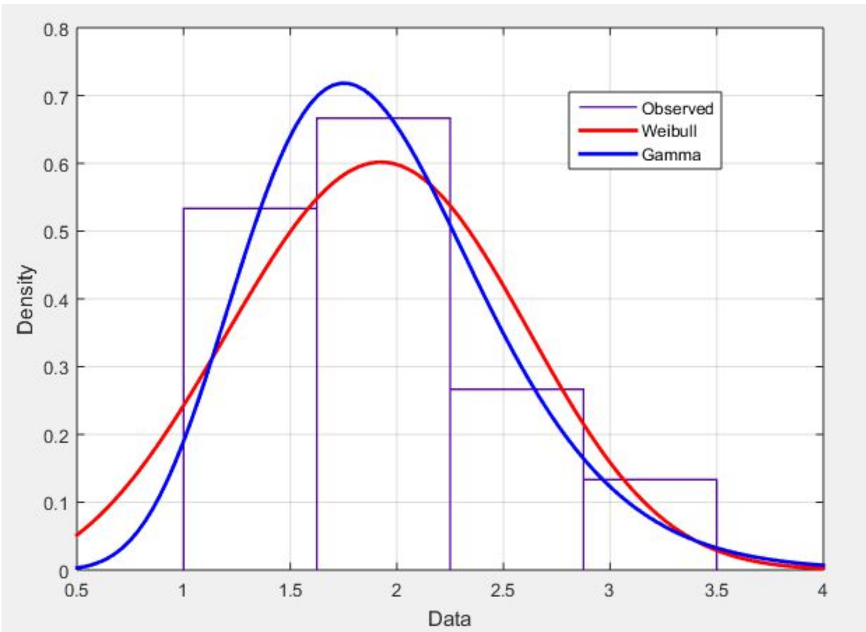

Figure 98: PDF- Girne -2002

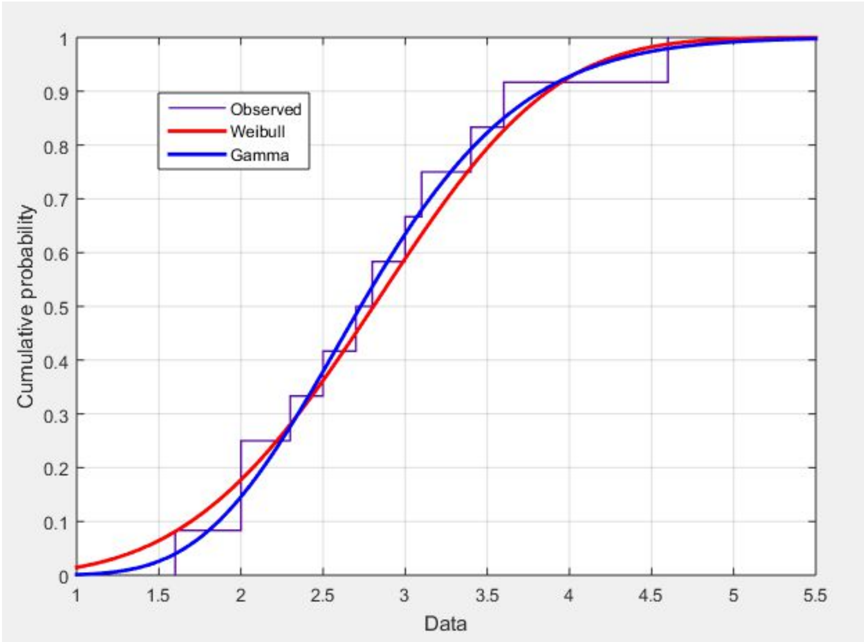

Figure 99: CDF- Girne -2003

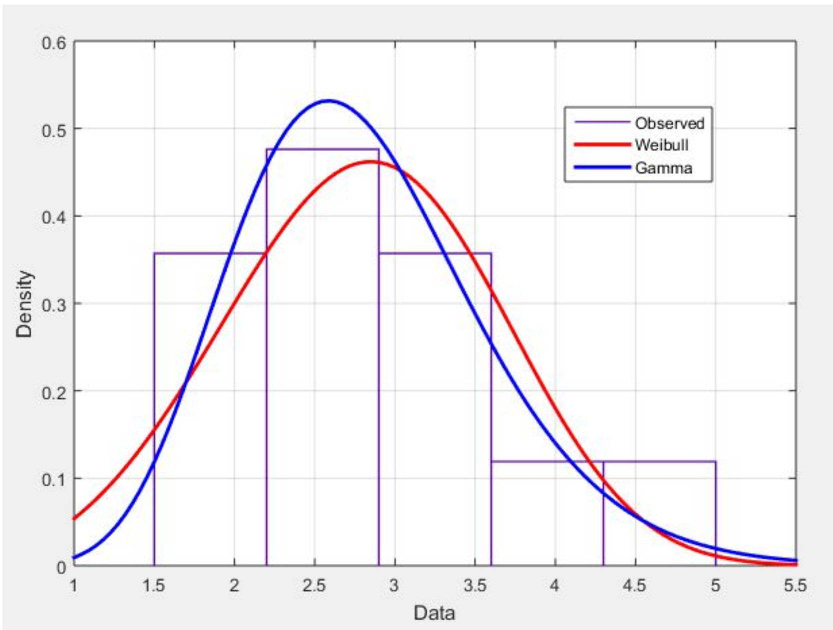

Figure 100: PDF- Girne -2003

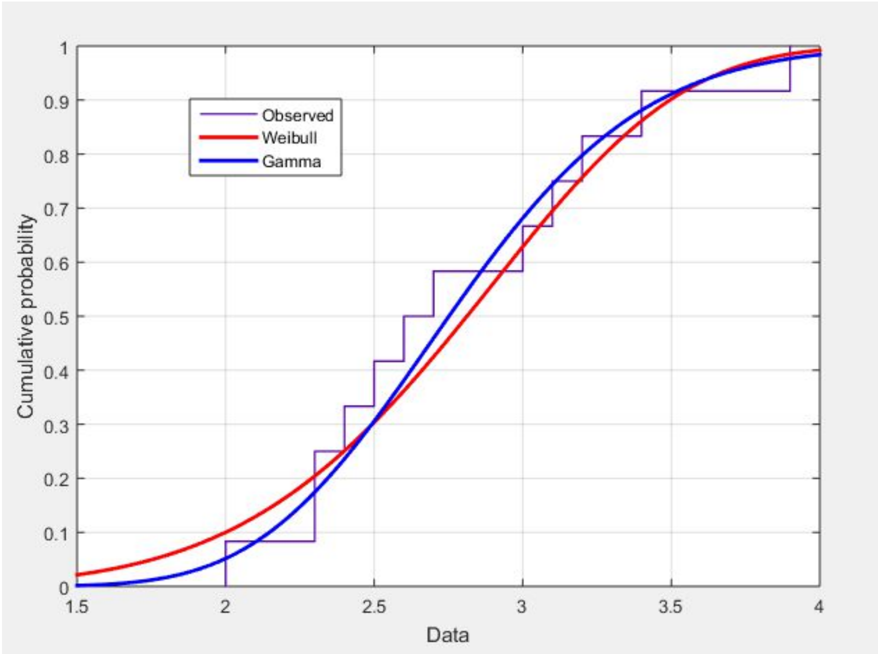

Figure 101: CDF- Girne -2004

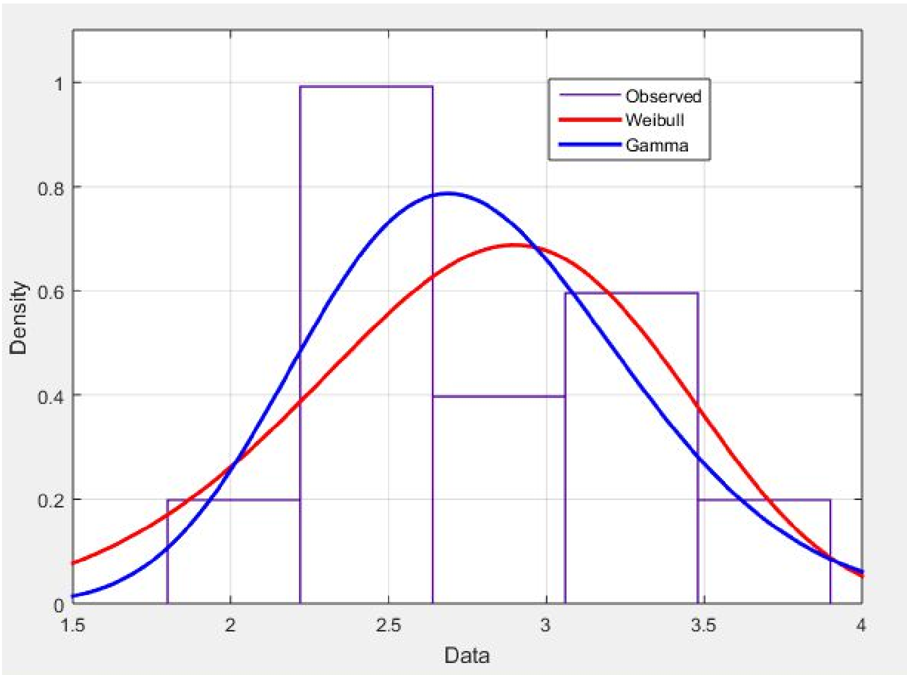

Figure 102: PDF- Girne -2004

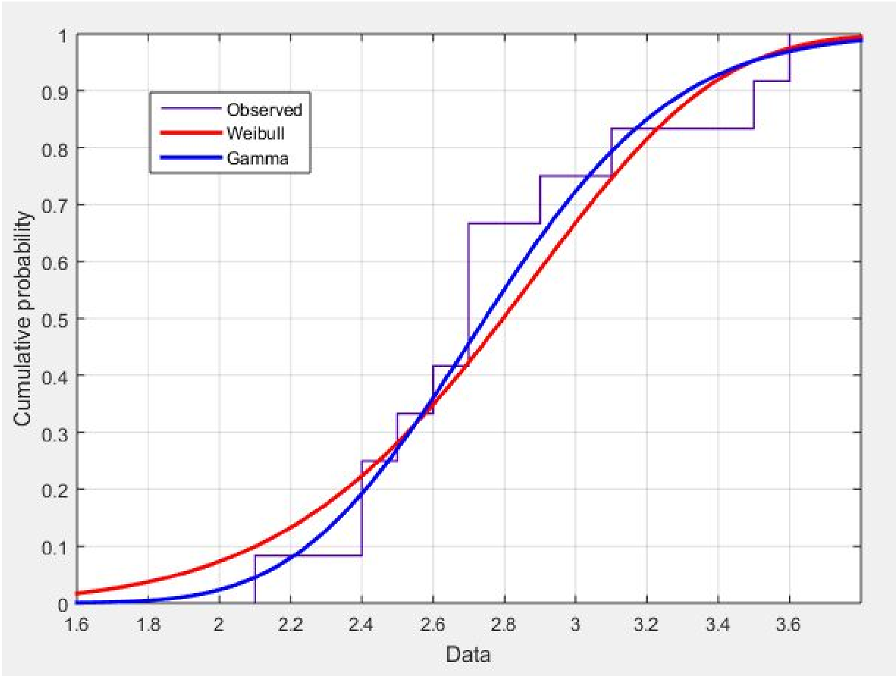

Figure 103: CDF- Girne -2005

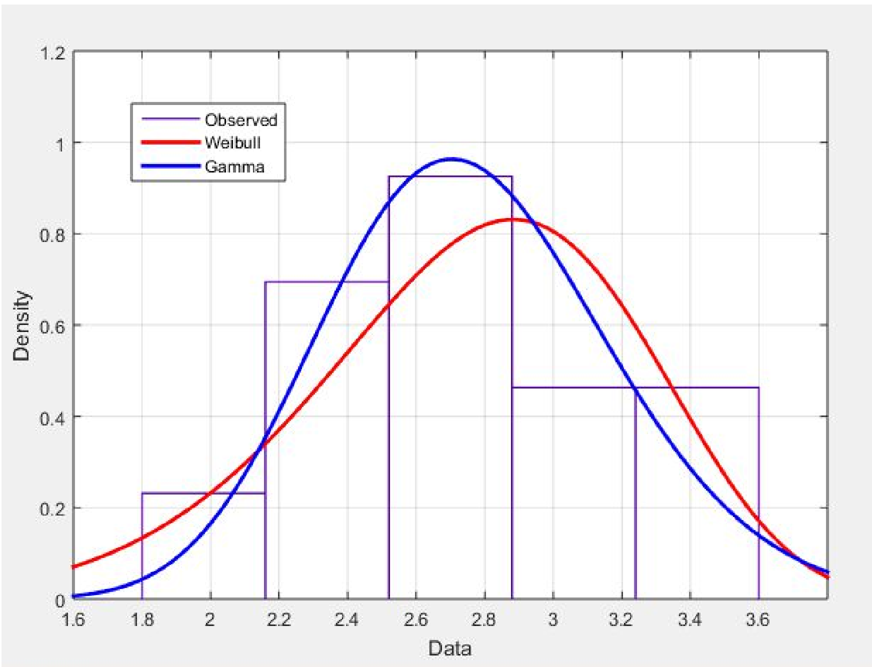

Figure 104: PDF- Girne -2005

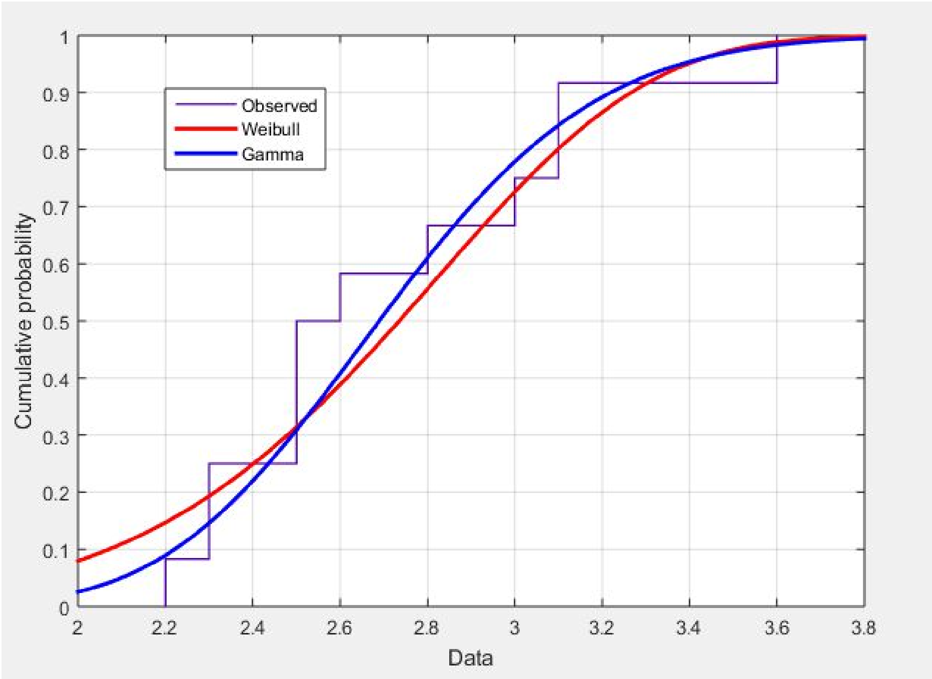

Figure 105: CDF- Girne -2006

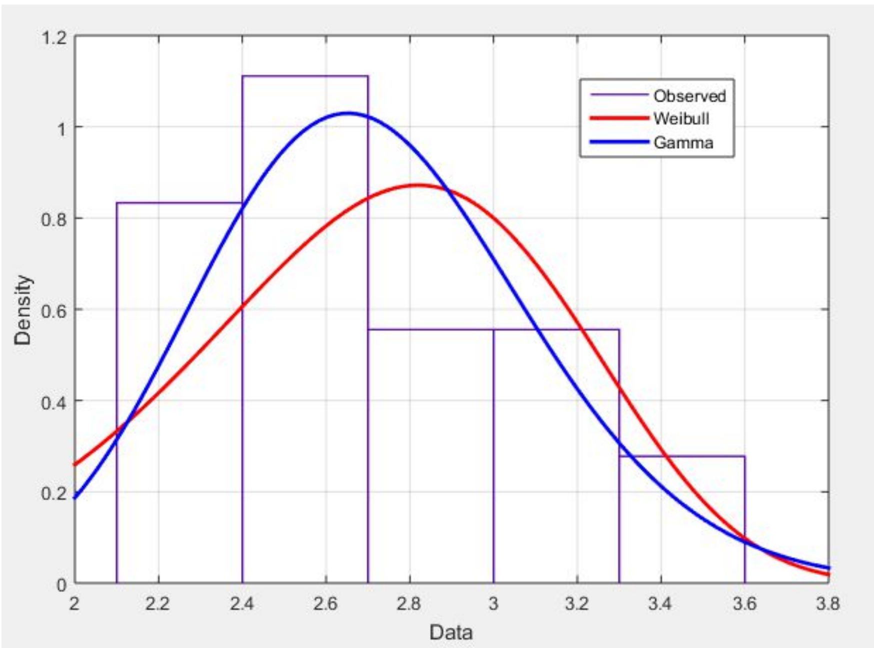

Figure 106: PDF- Girne -2006

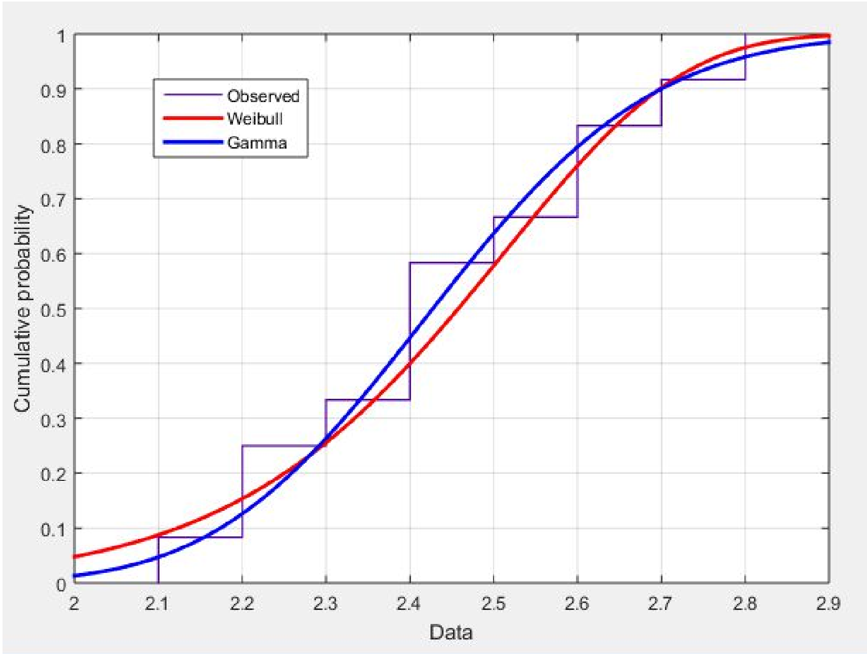

Figure 107: CDF- Girne -2007

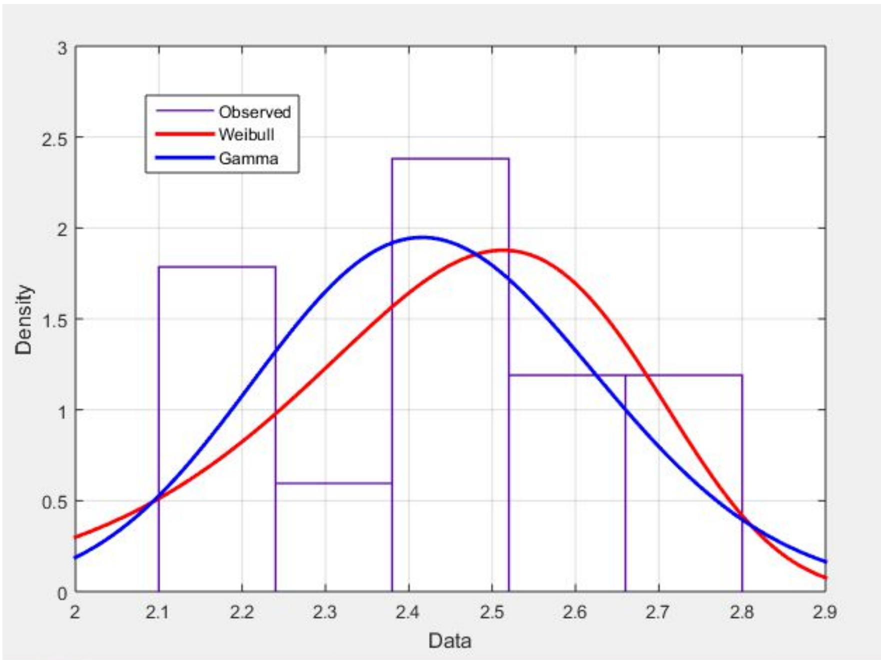

Figure 108: PDF- Girne -2007

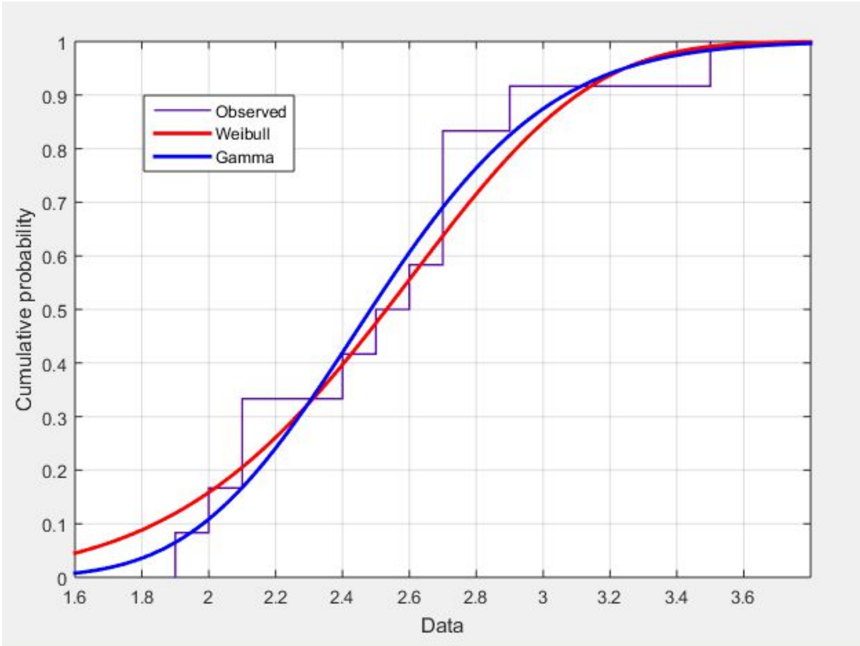

Figure 109: CDF- Girne -2008

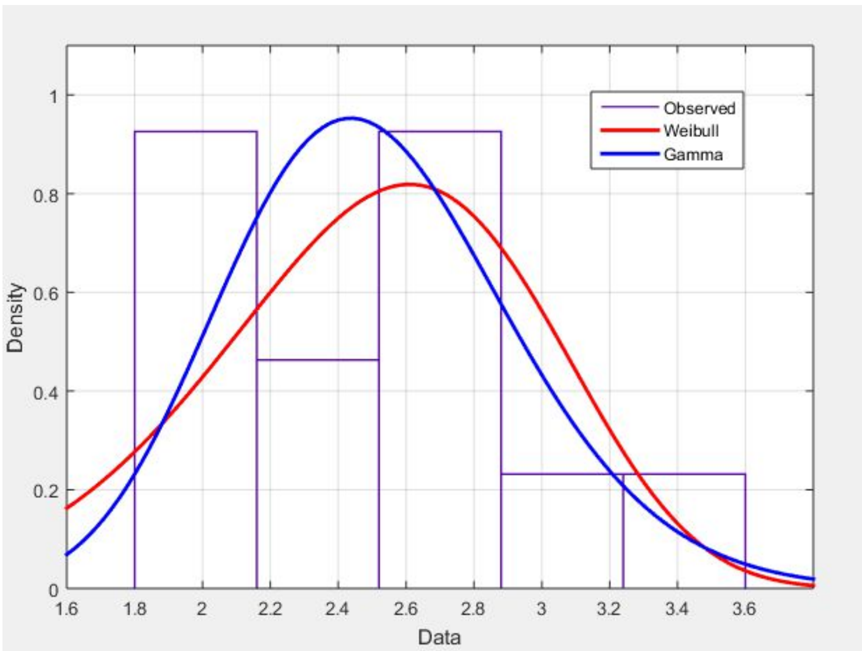

Figure 110: PDF- Girne -2008

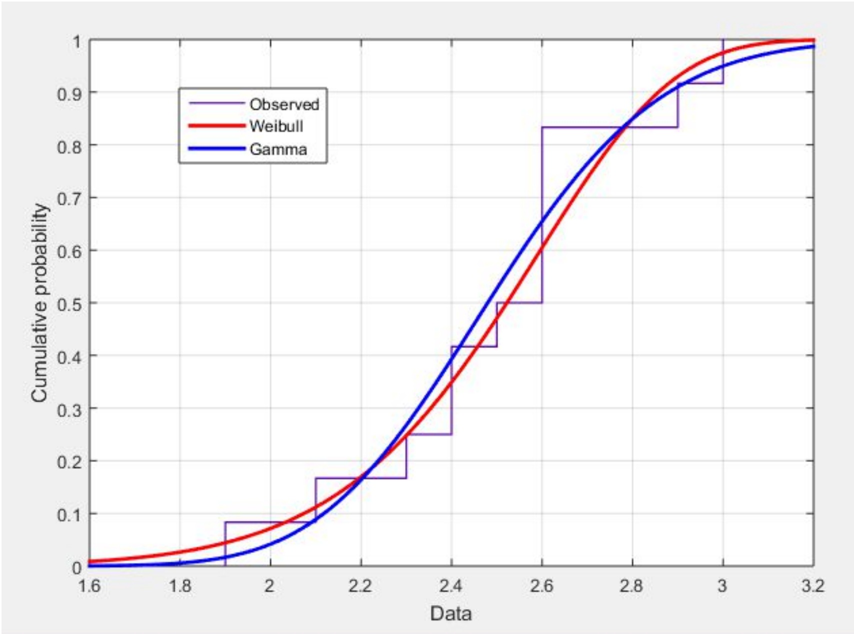

Figure 111: CDF- Girne -2009

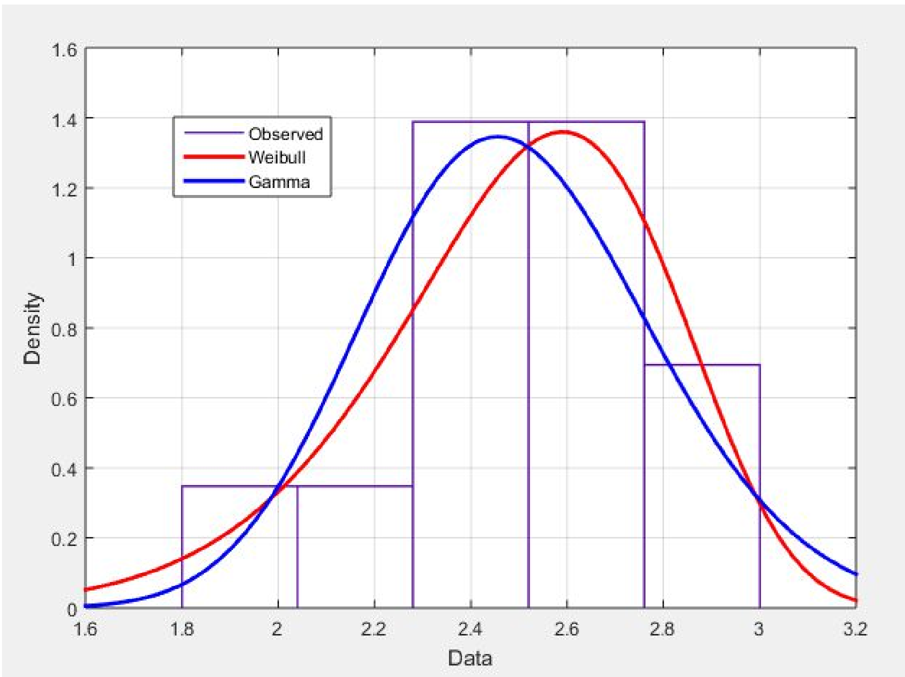

Figure 112: PDF- Girne -2009

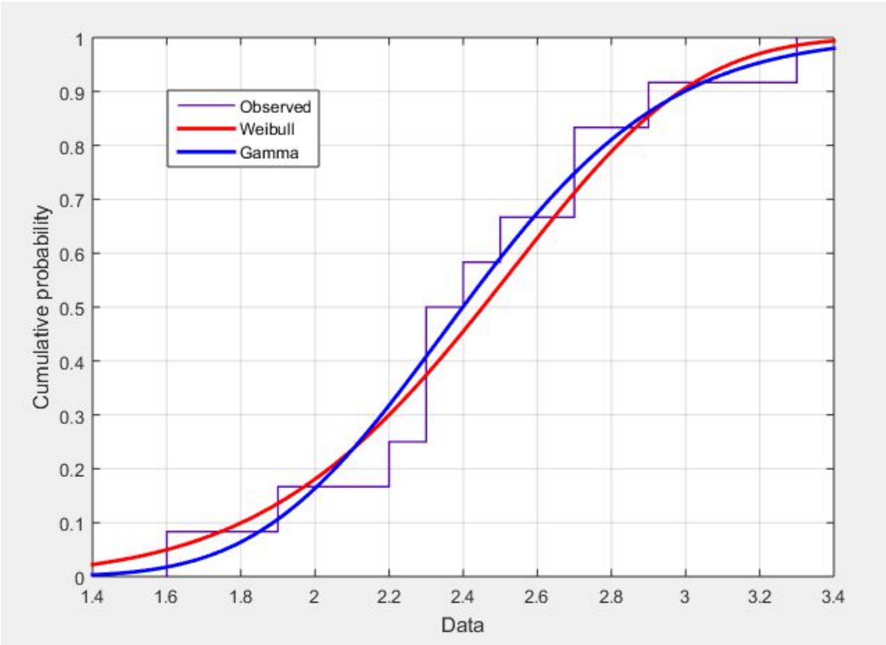

Figure 113 CDF- Girne -2010

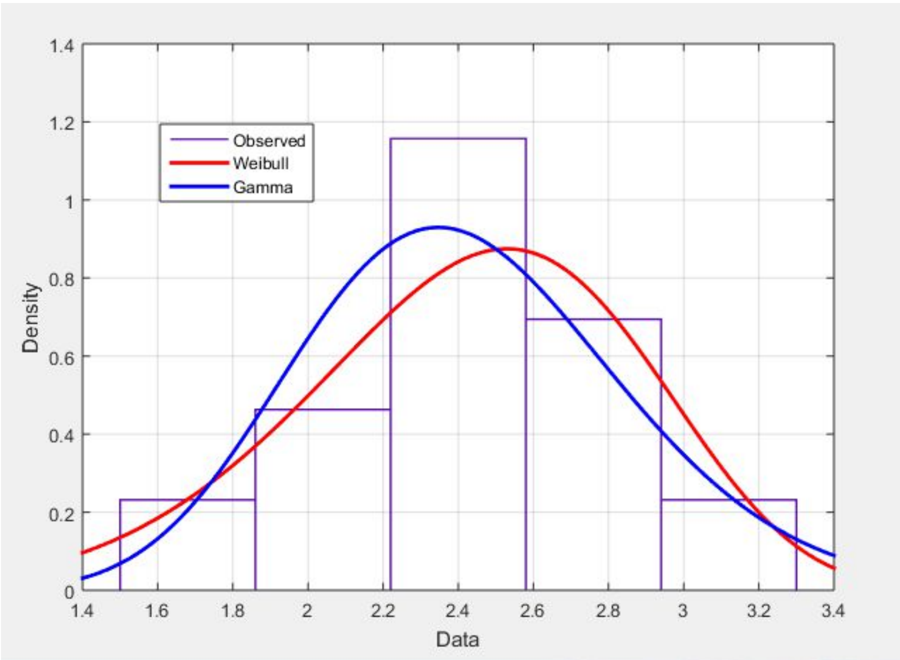

Figure 114: PDF- Girne -2010

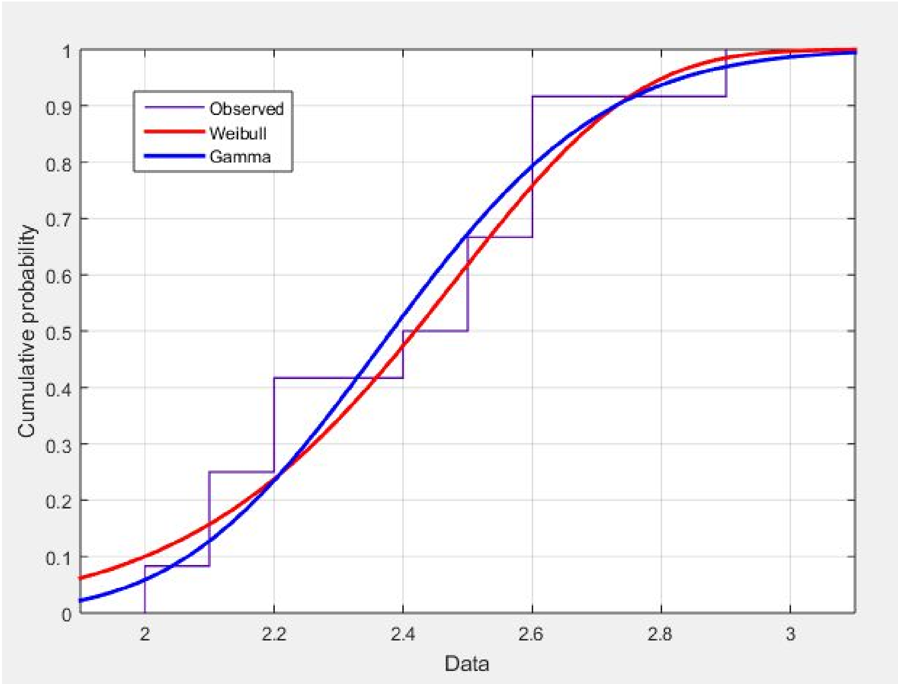

Figure 115: CDF- Girne -2011

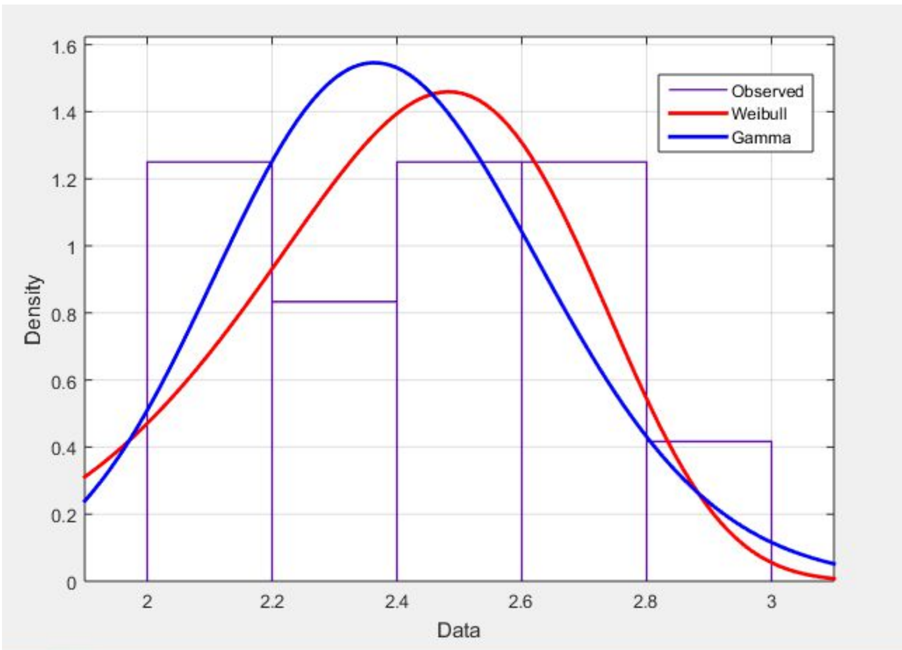

Figure 116: PDF- Girne -2011

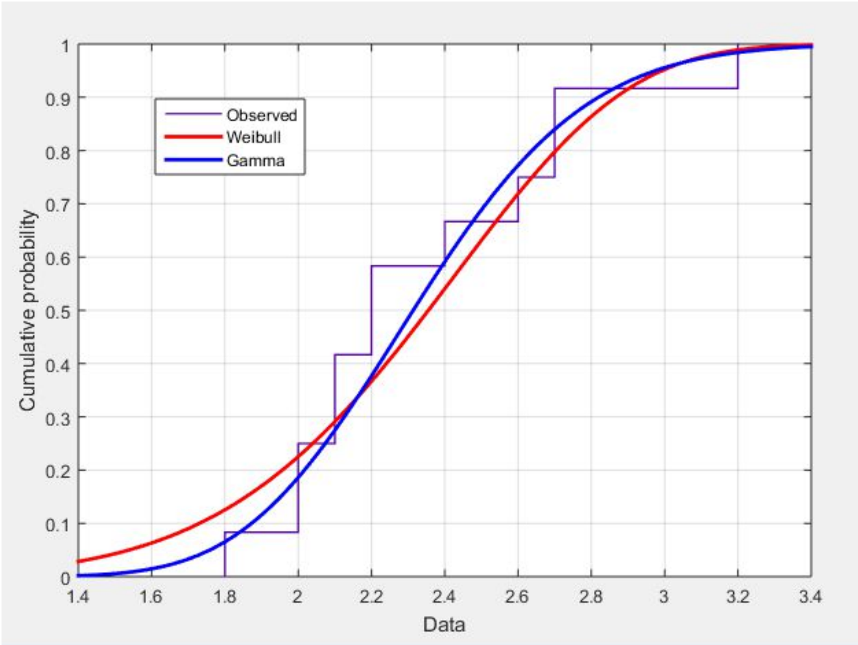

Figure 117: CDF- Girne -2012

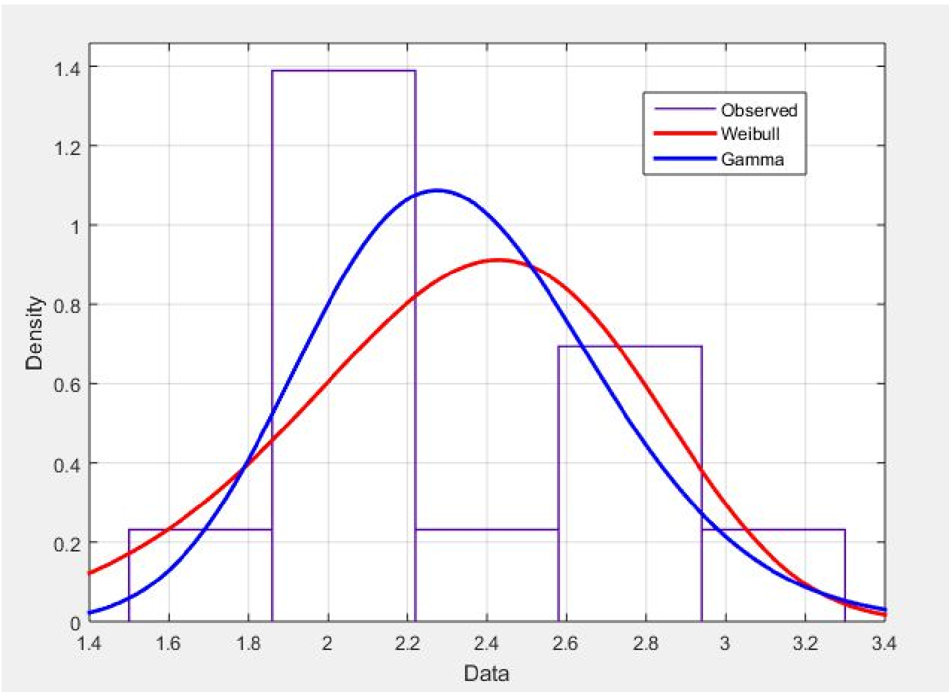

Figure 118: PDF- Girne -2012

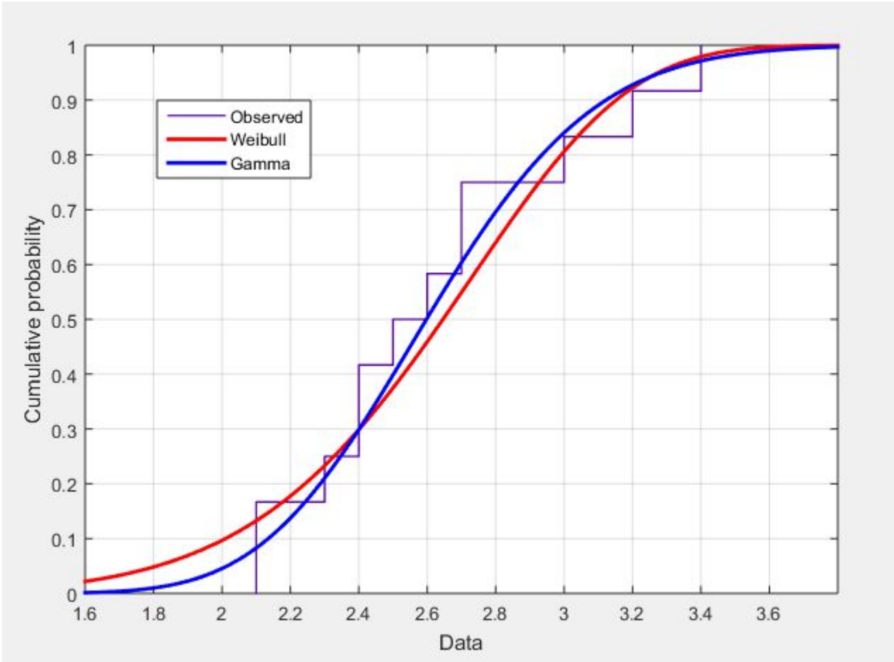

Figure 119: CDF- Girne -2013

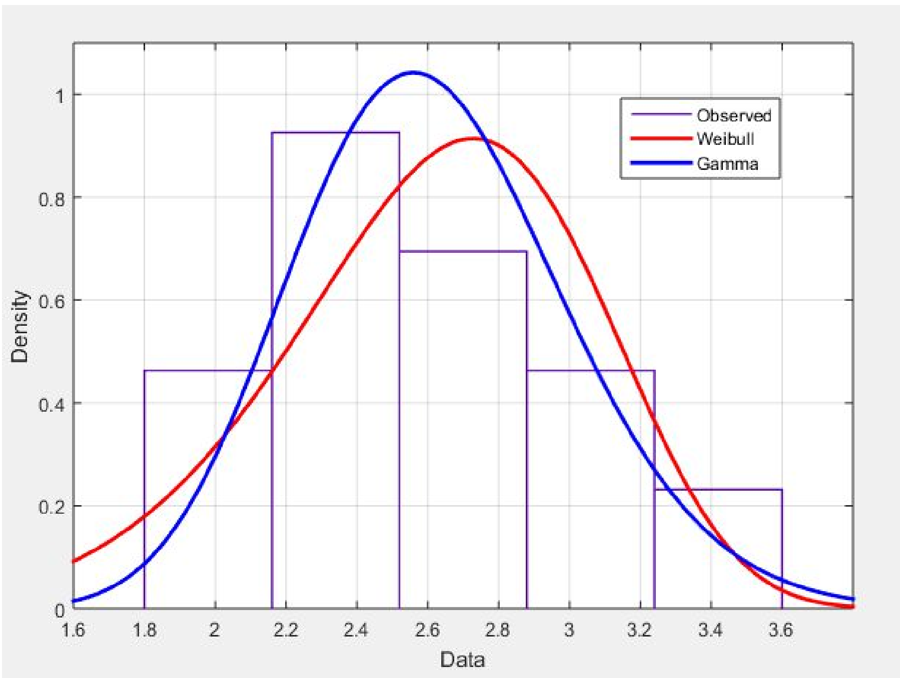

Figure 120 PDF- Girne -2013

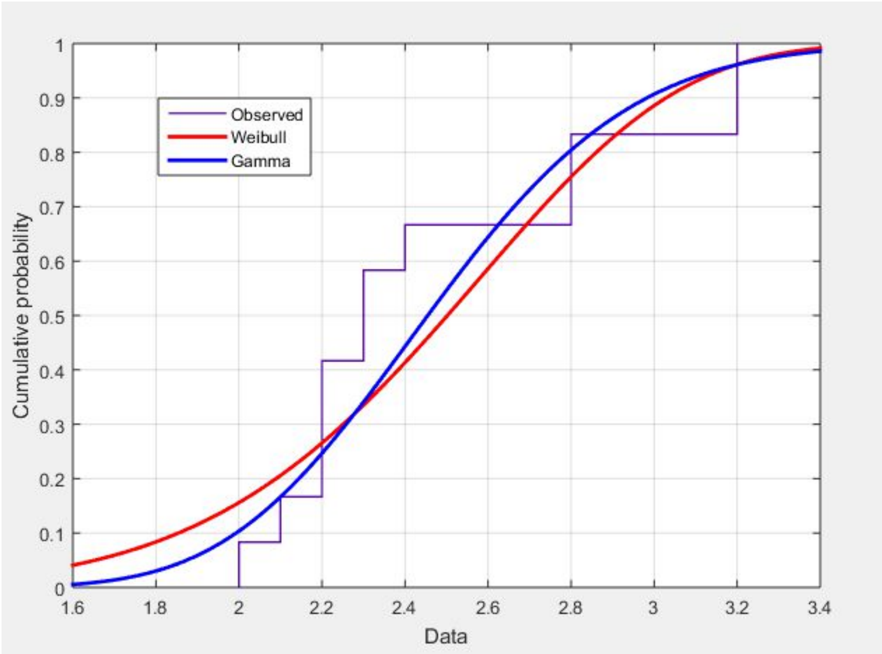

Figure 121: CDF- Girne -2014

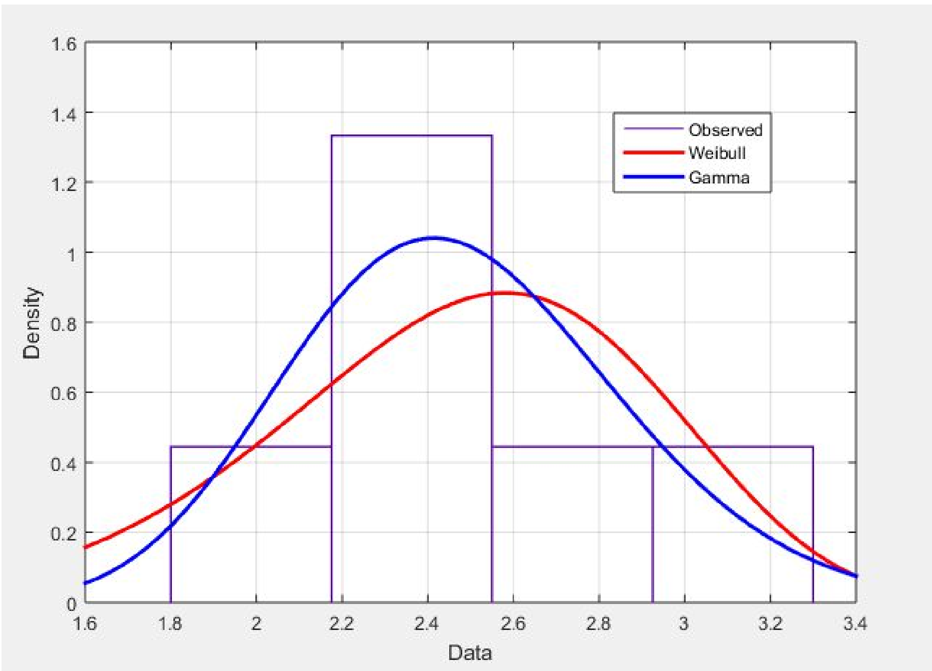

Figure 122: PDF- Girne -2014

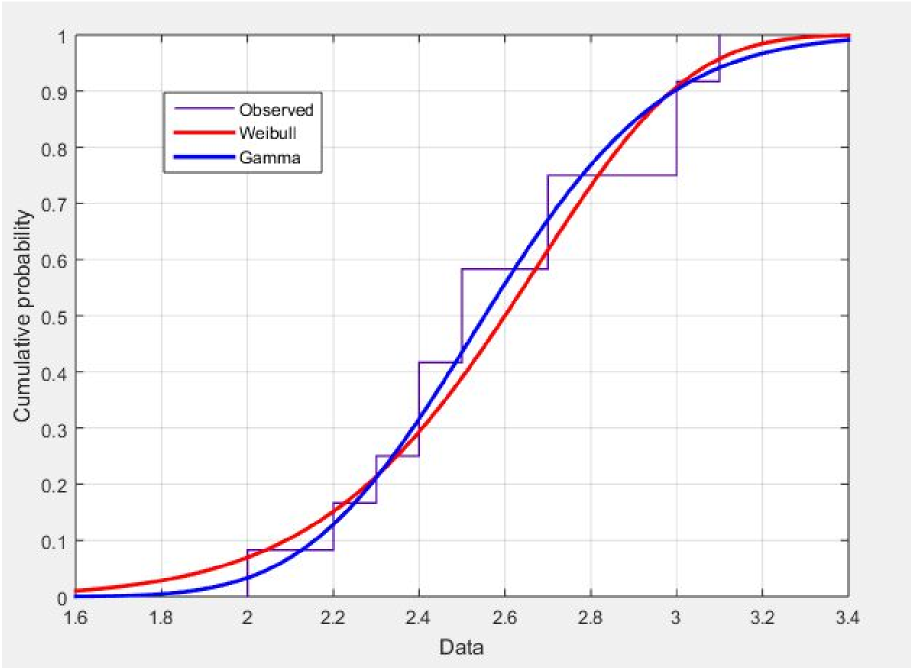

Figure 123: CDF- Girne -2015

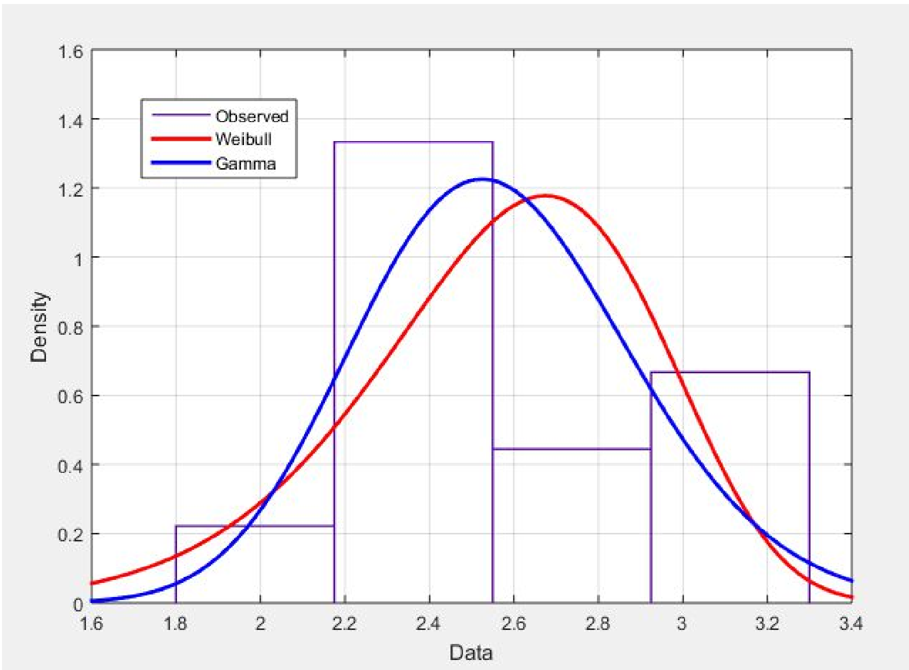

Figure 124: PDF- Girne -2015

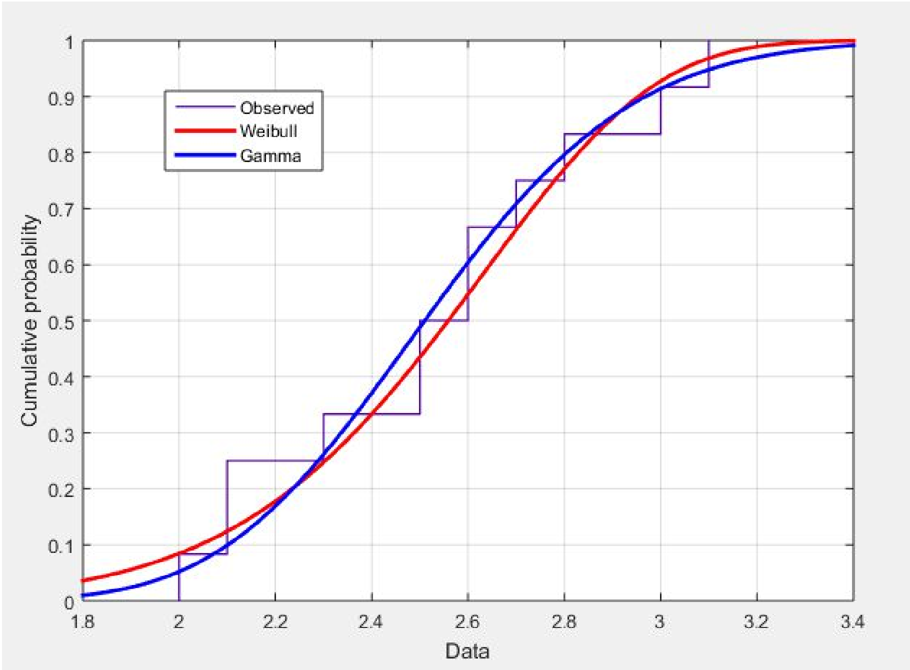

Figure 125: CDF- Girne -2016

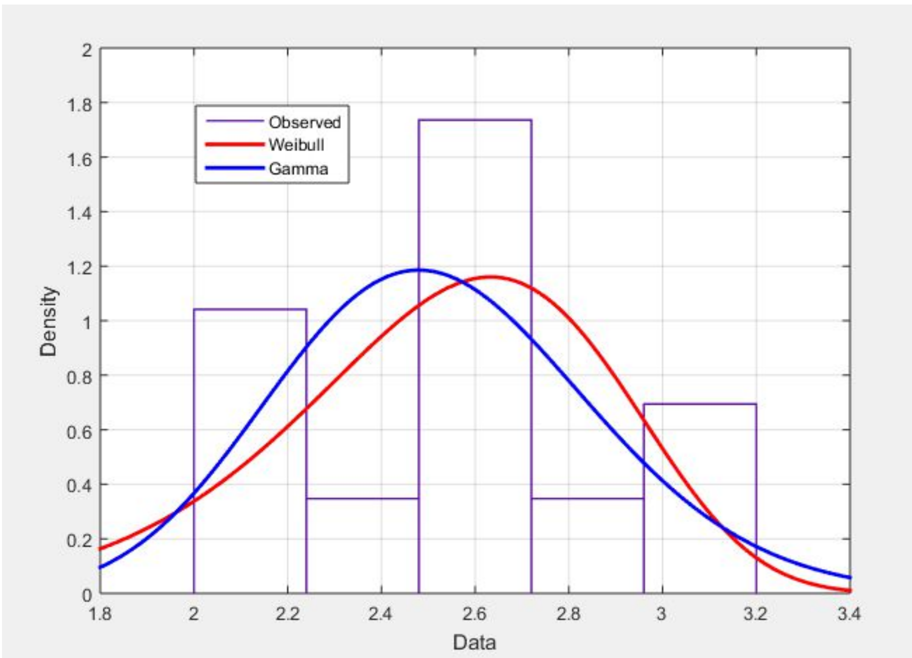

Figure 126: PDF- Girne -2016

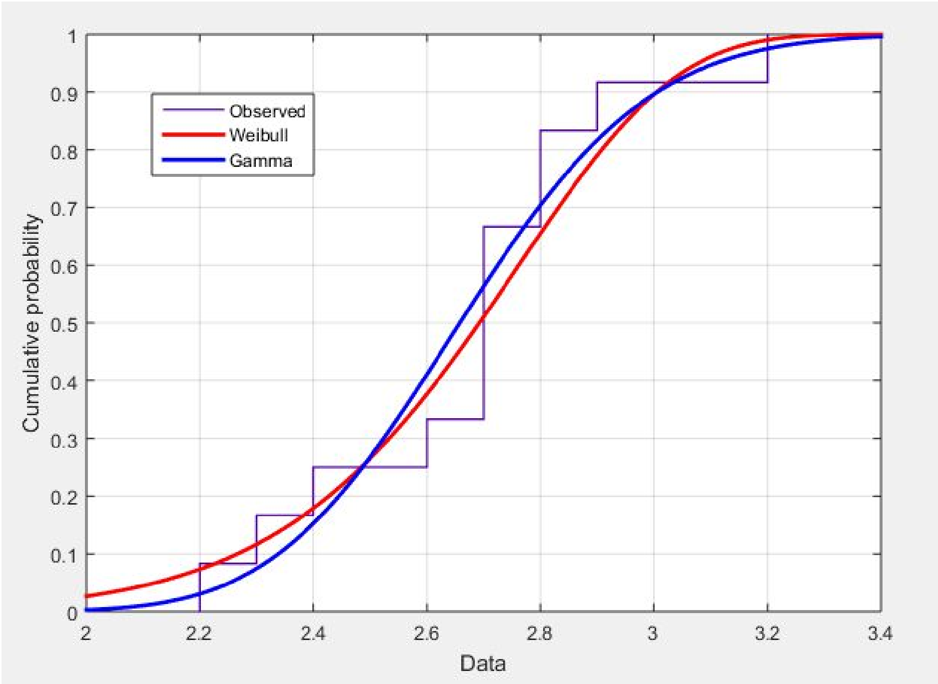

Figure 127: CDF-Güzelyurt-2000

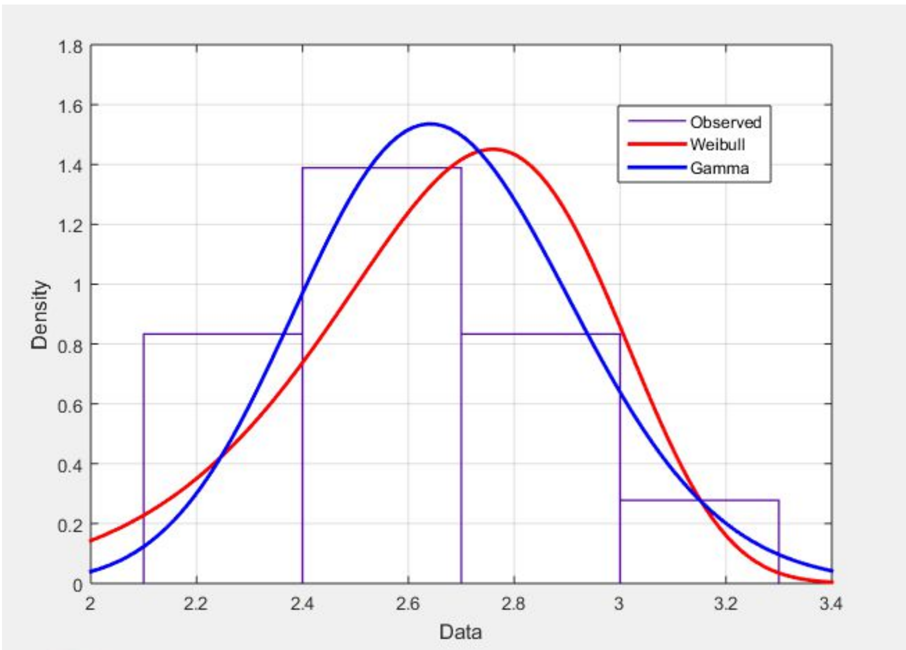

Figure 128: PDF- Güzelyurt -2000

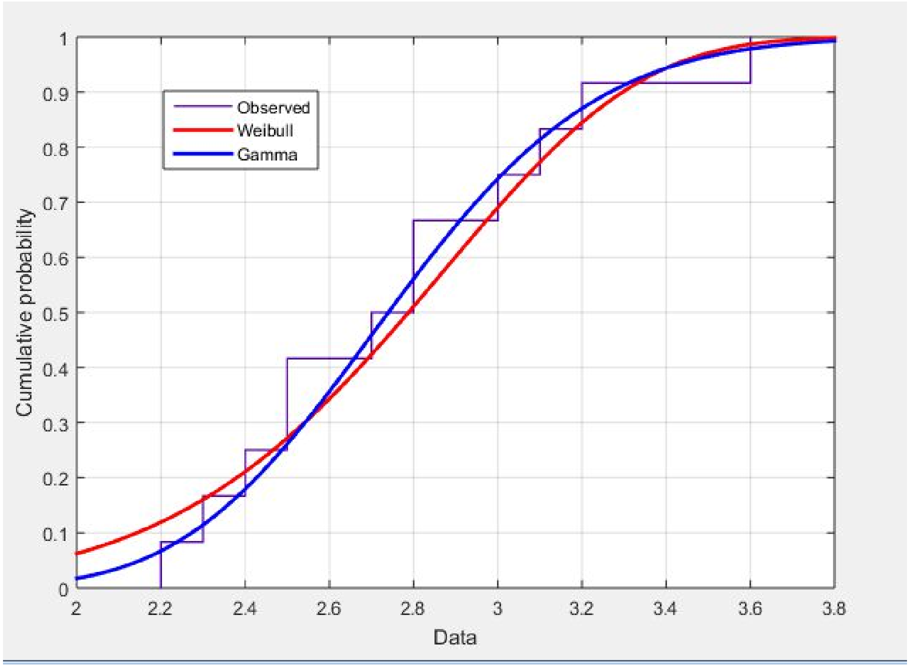

Figure 129: CDF- Güzelyurt -2001

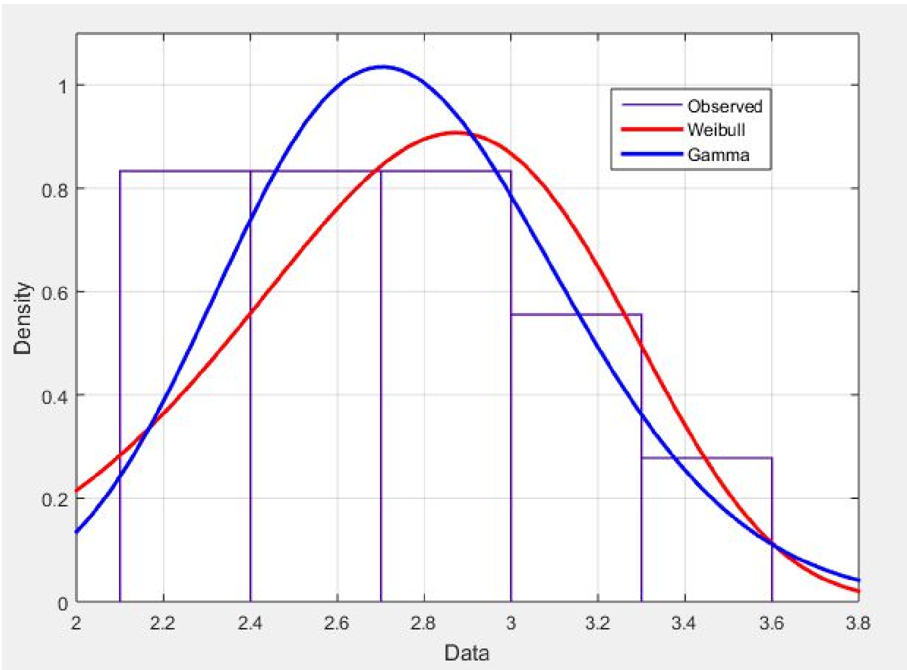

Figure 130: PDF- Güzelyurt -2001

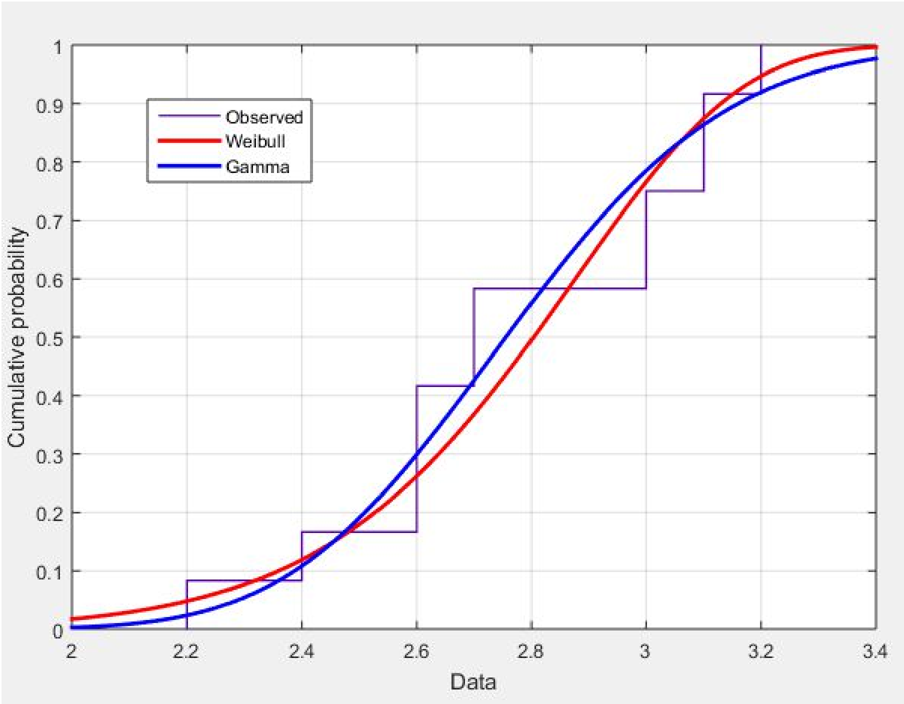

Figure 131: CDF- Güzelyurt -2002

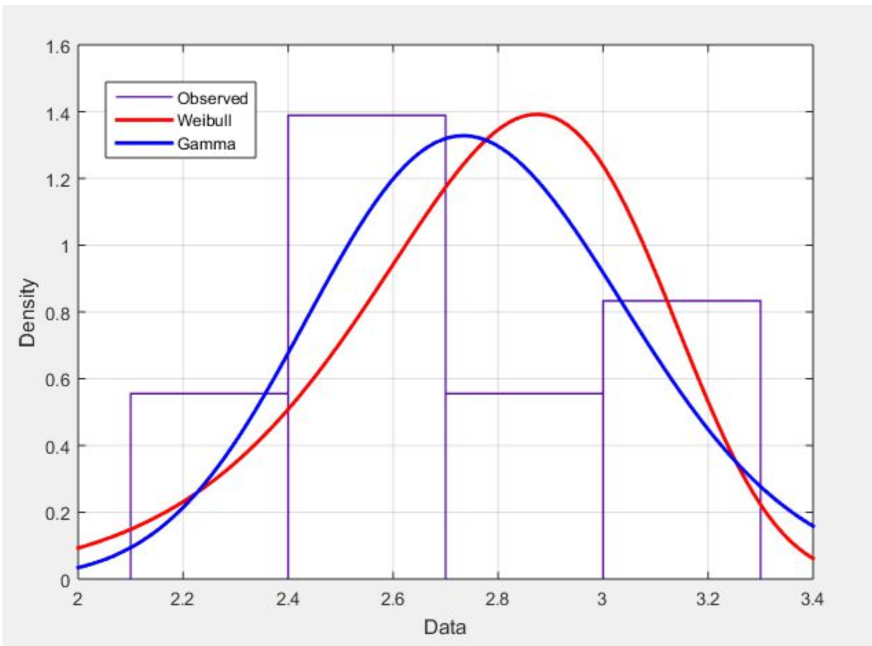

Figure 132: PDF- Güzelyurt -2002

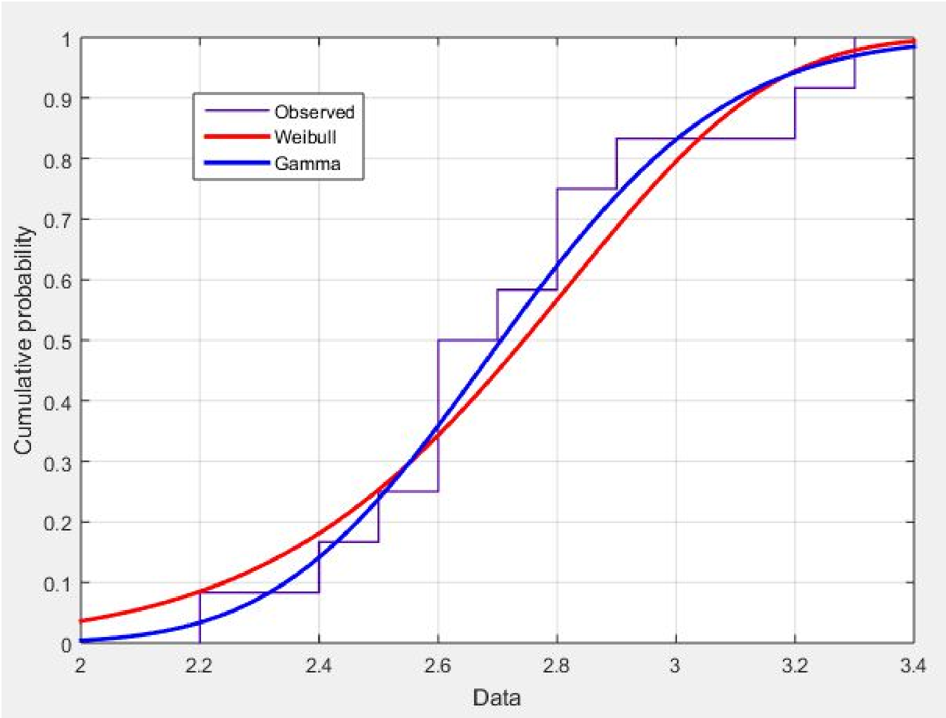

Figure 133: CDF-Güzelyurt-2003

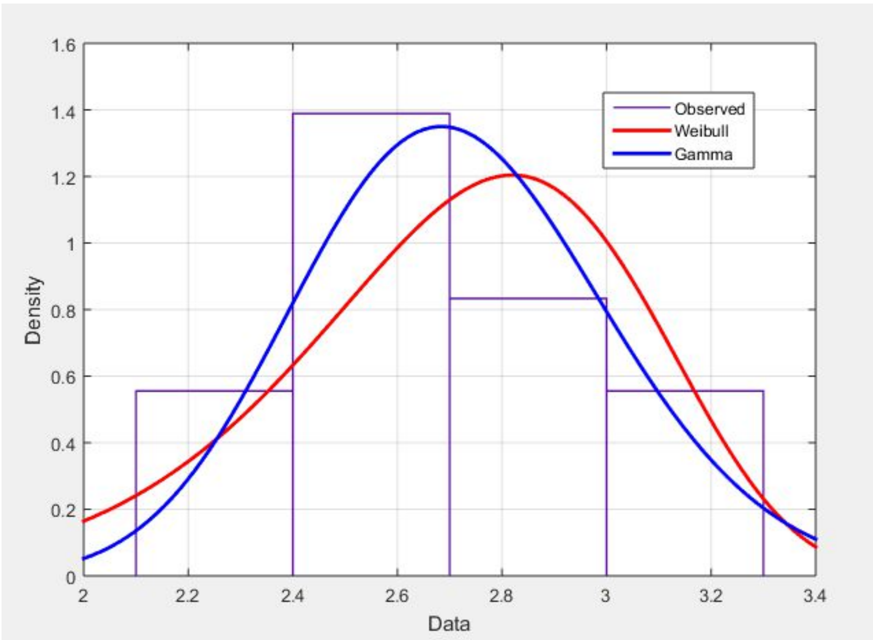

Figure 134: PDF-Güzelyurt-2003

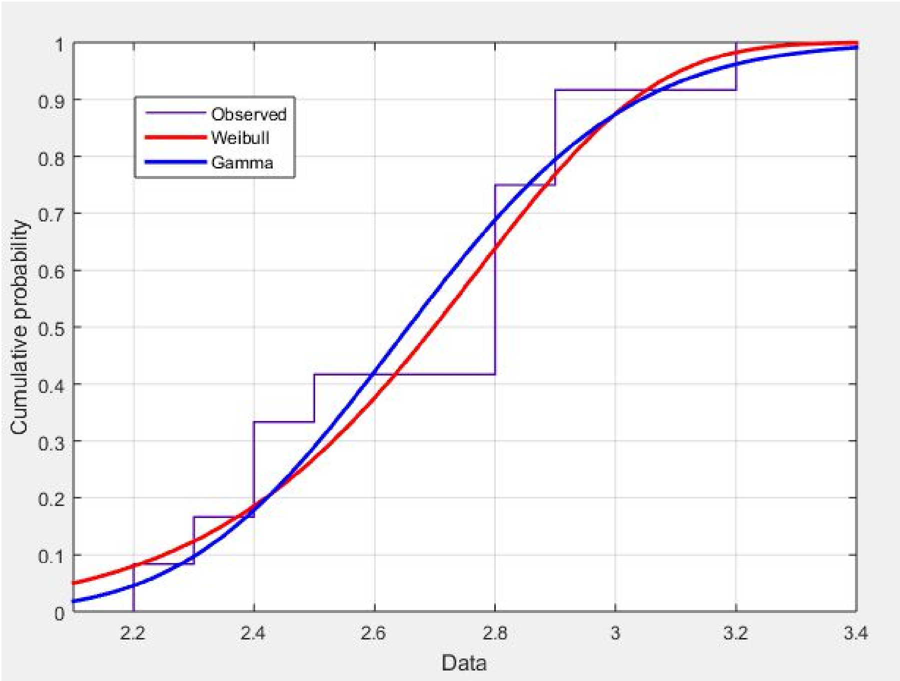

Figure 135: CDF-Güzelyurt-2004

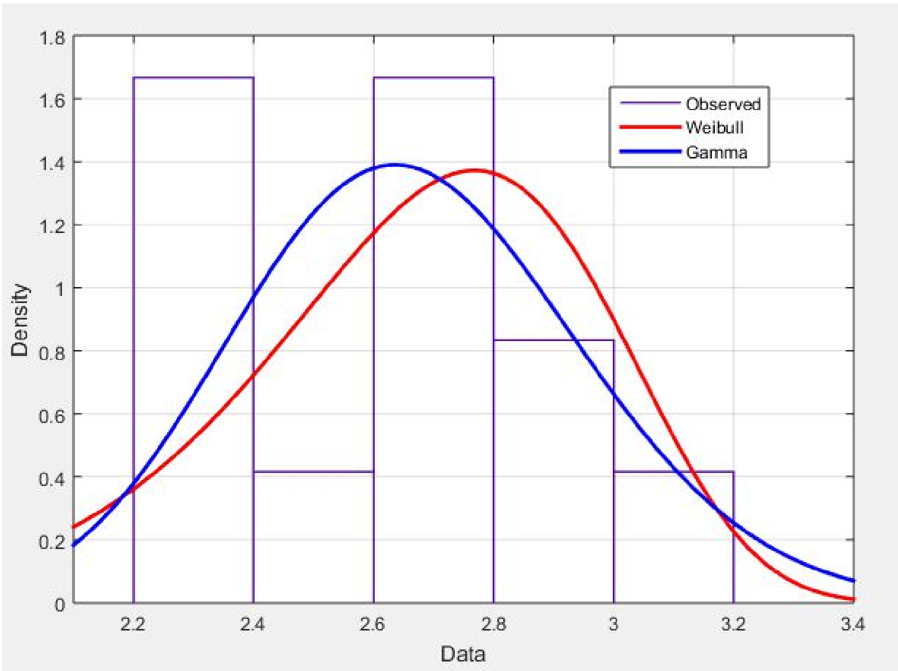

Figure 136: PDF-Güzelyurt-2004

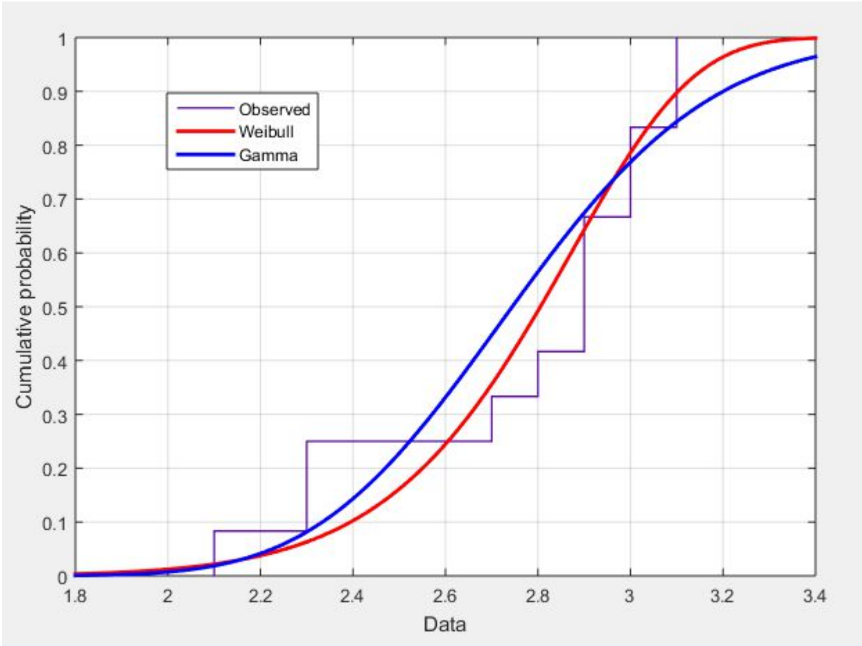

Figure 137: CDF-Güzelyurt-2005

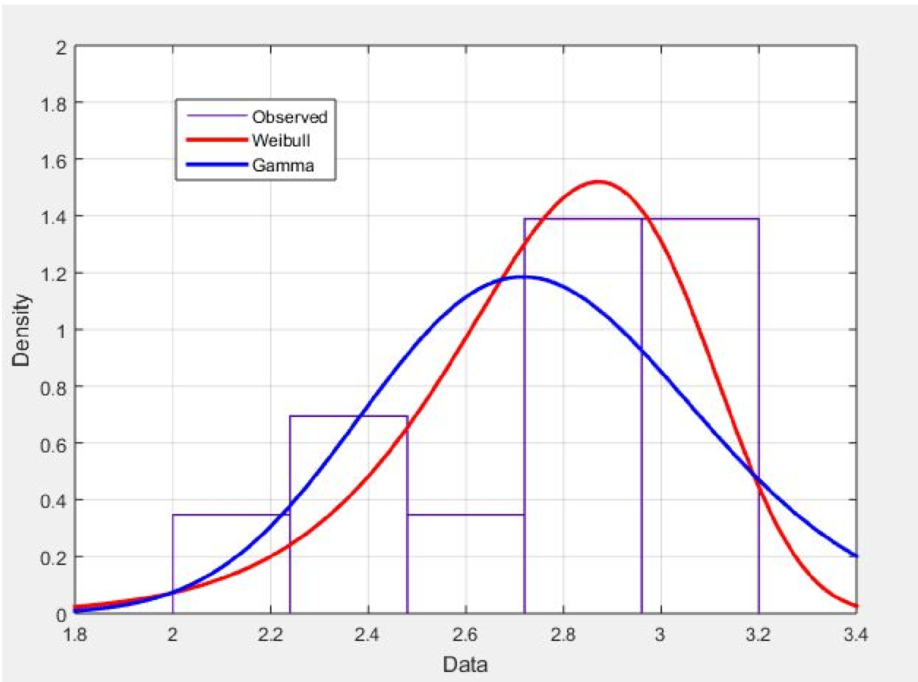

Figure 138: PDF-Güzelyurt-2005

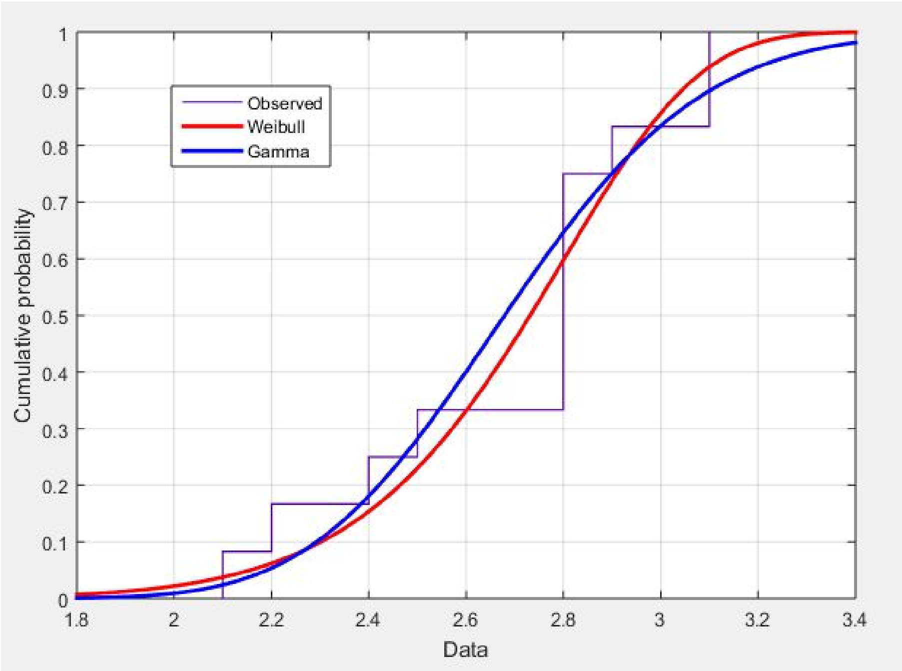

Figure 139: CDF-Güzelyurt-2006

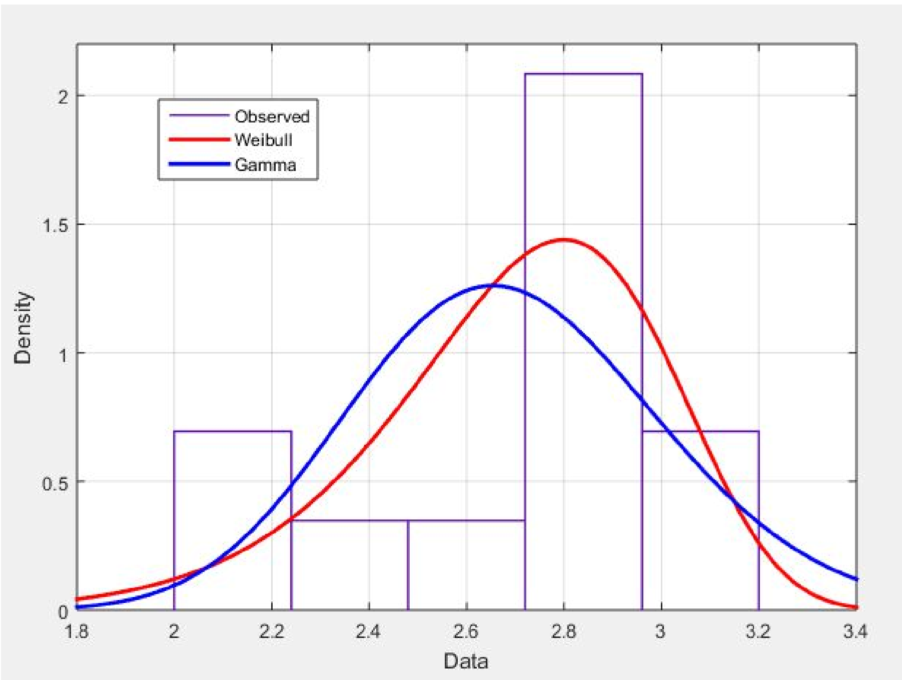

Figure 140: PDF-Güzelyurt-2006

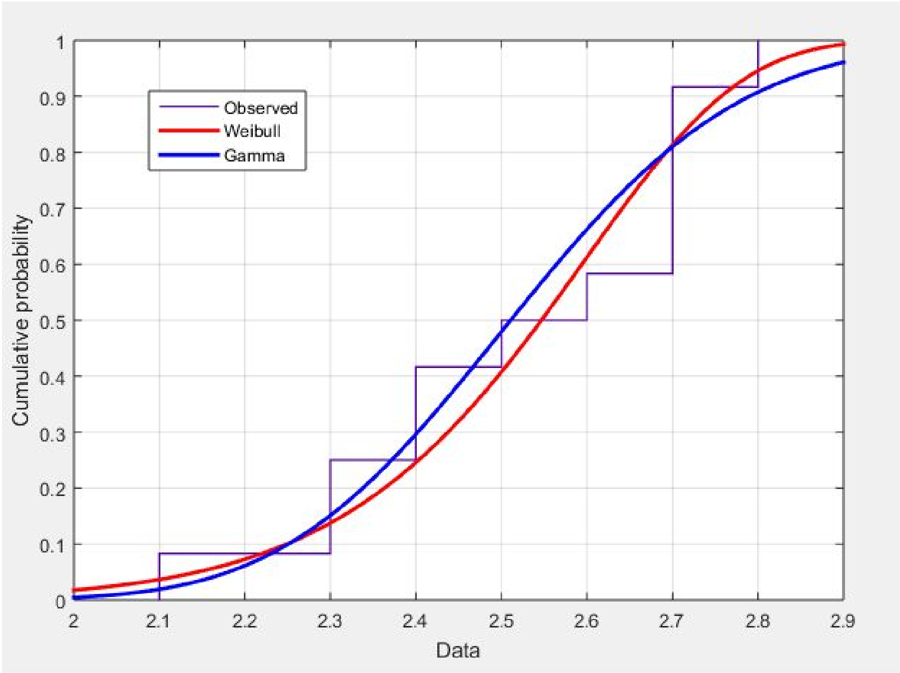

Figure 141: CDF-Güzelyurt-2007

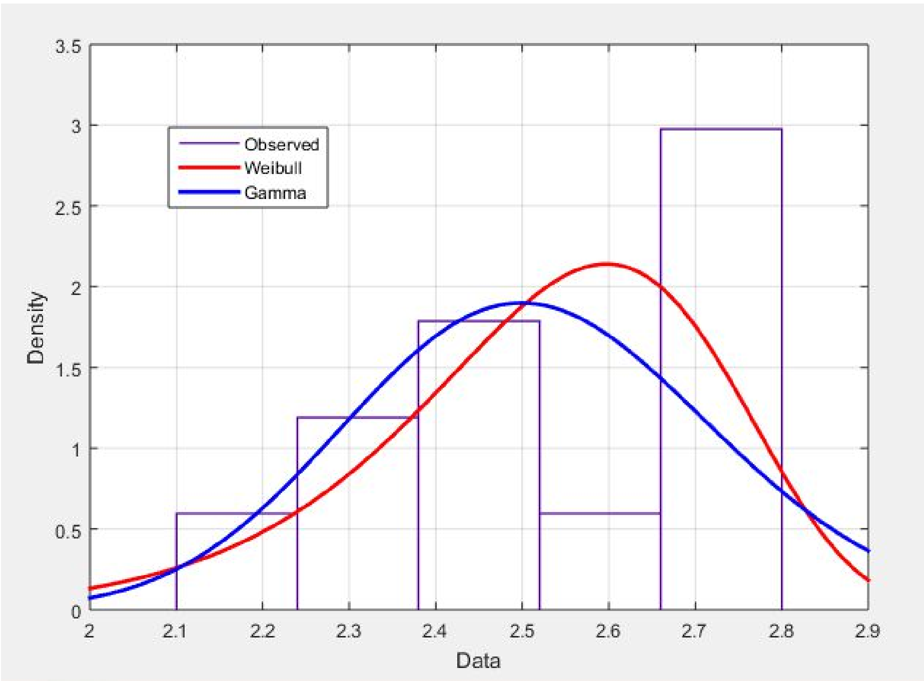

Figure 142: PDF-Güzelyurt-2007

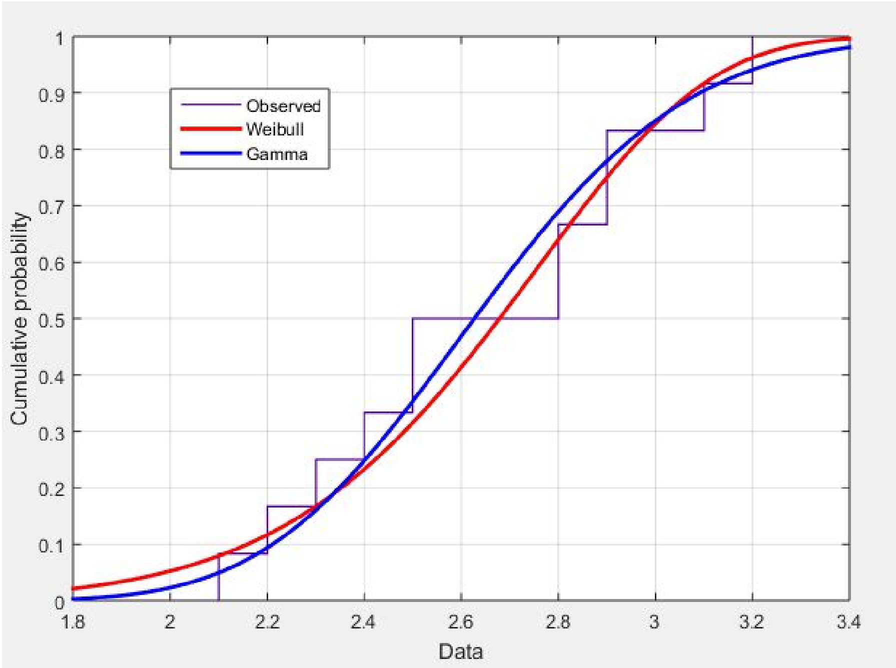

Figure 143: CDF-Güzelyurt-2008

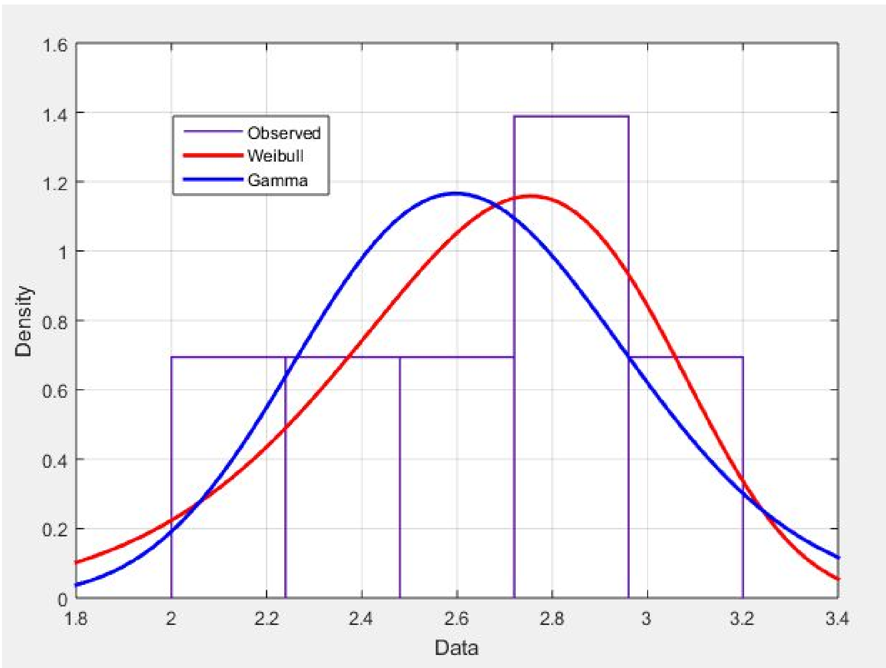

Figure 144: PDF-Güzelyurt-2008

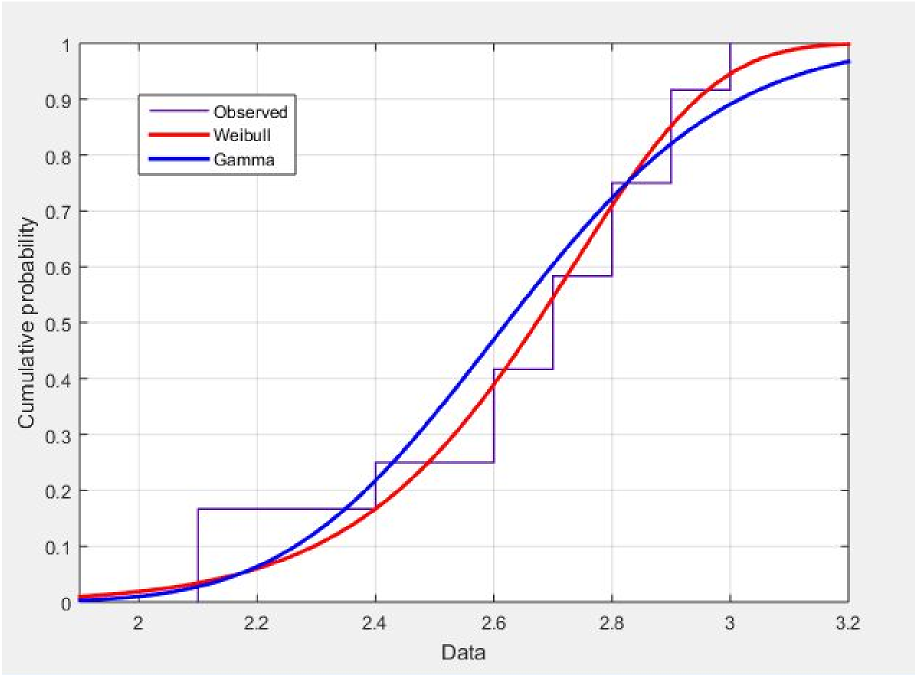

Figure 145: CDF-Güzelyurt-2009

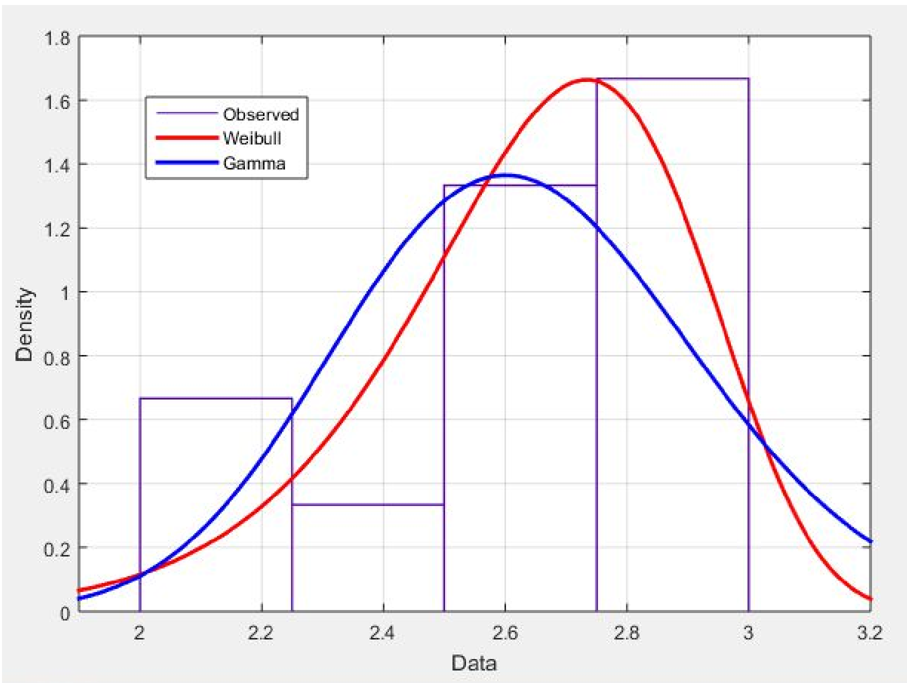

Figure 146: PDF-Güzelyurt-2009

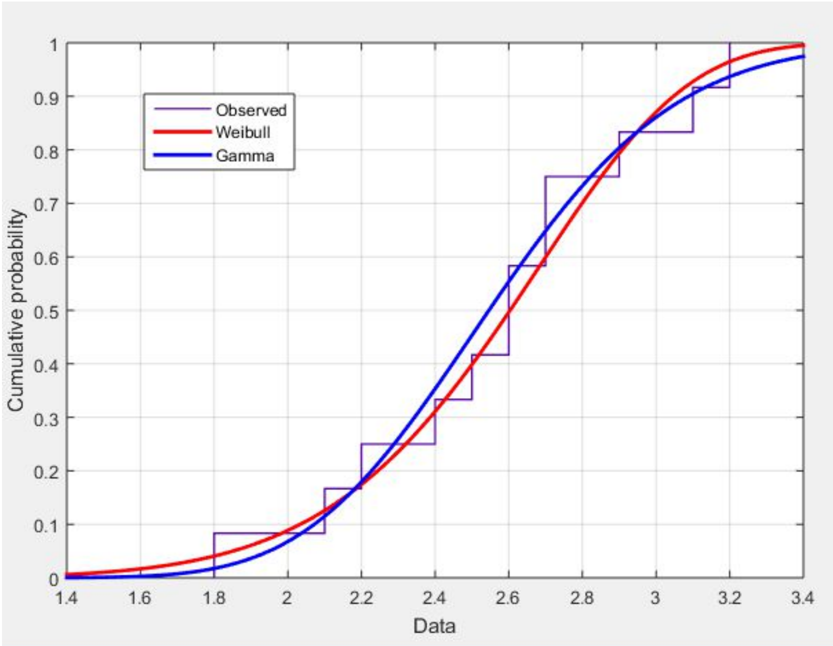

Figure 147: CDF-Güzelyurt-2010

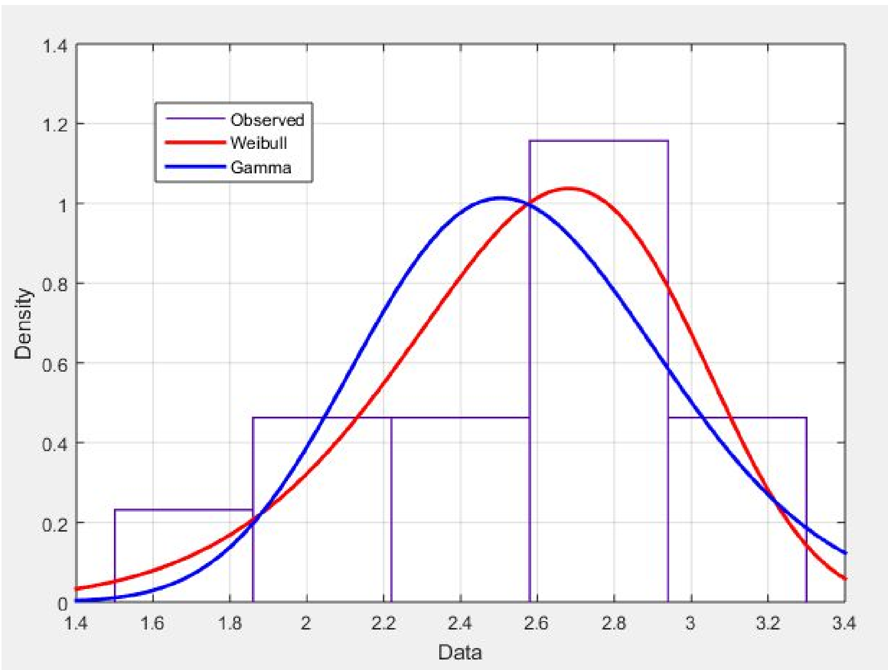

Figure 148: PDF-Güzelyurt-2010

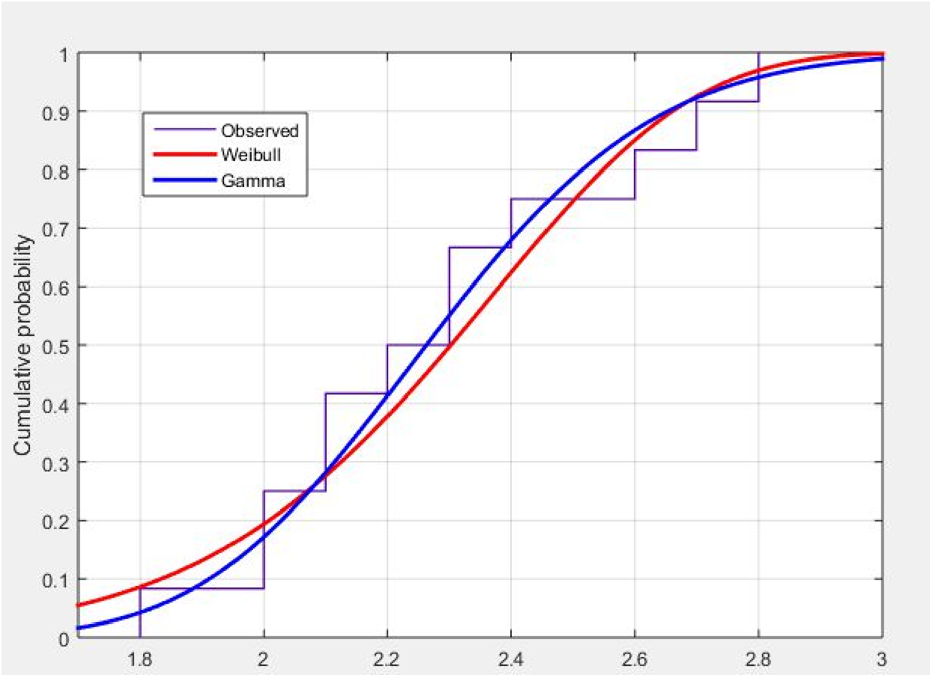

Figure 149: CDF-Güzelyurt-2011

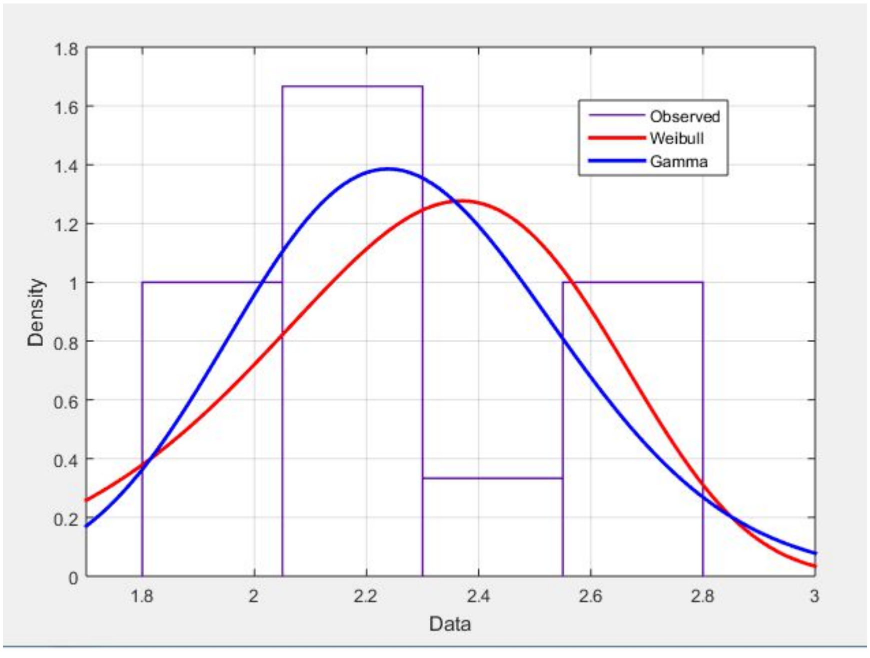

Figure 150: PDF-Güzelyurt-2011

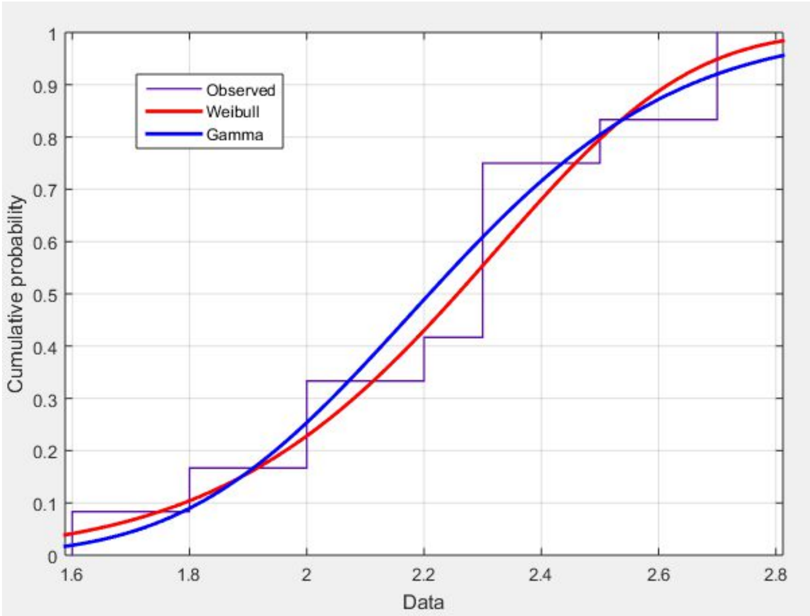

Figure 151: CDF-Güzelyurt-2012

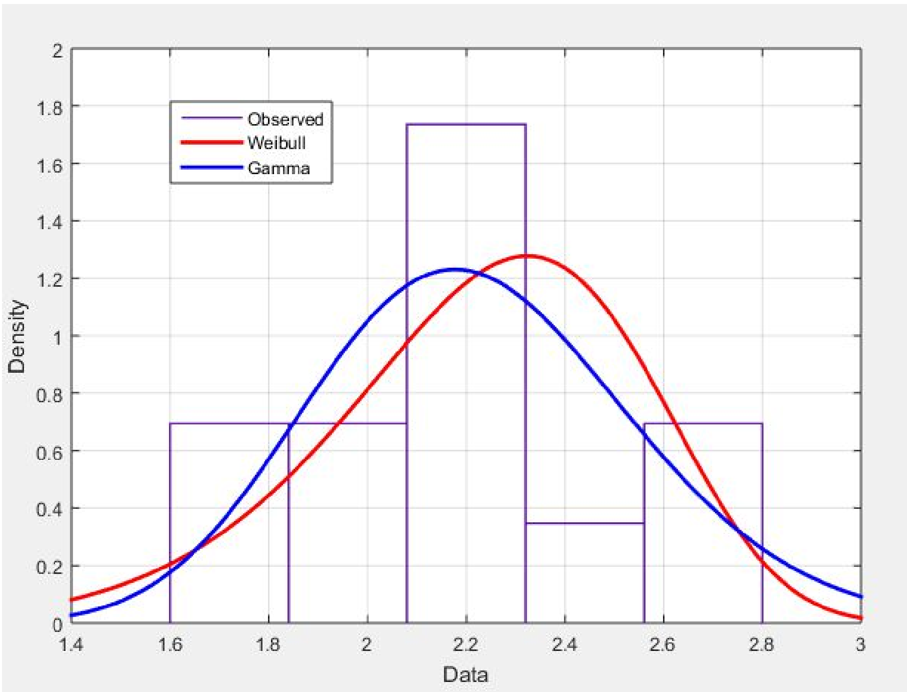

Figure 152: PDF-Güzelyurt-2012

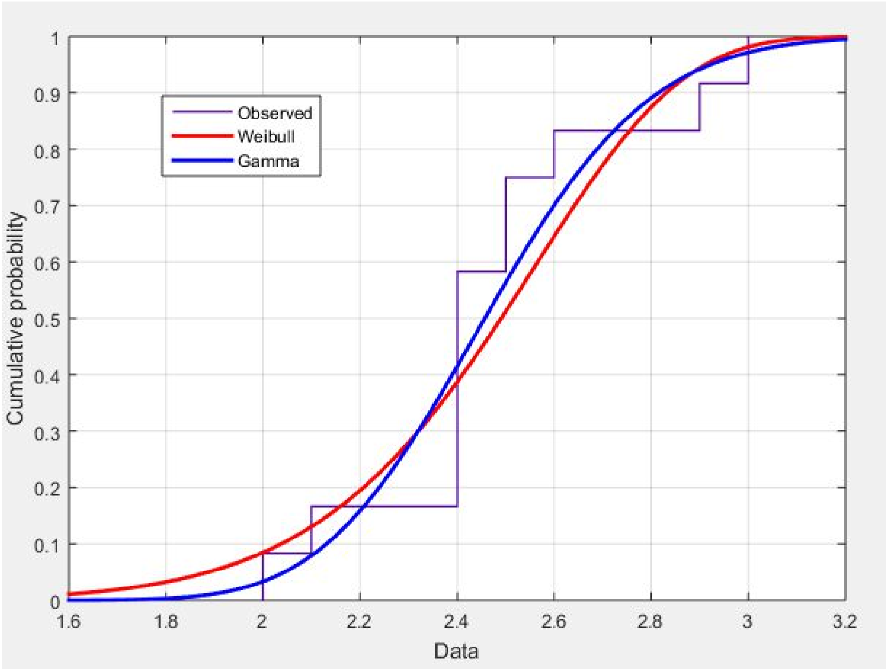

Figure 153: CDF-Güzelyurt-2013

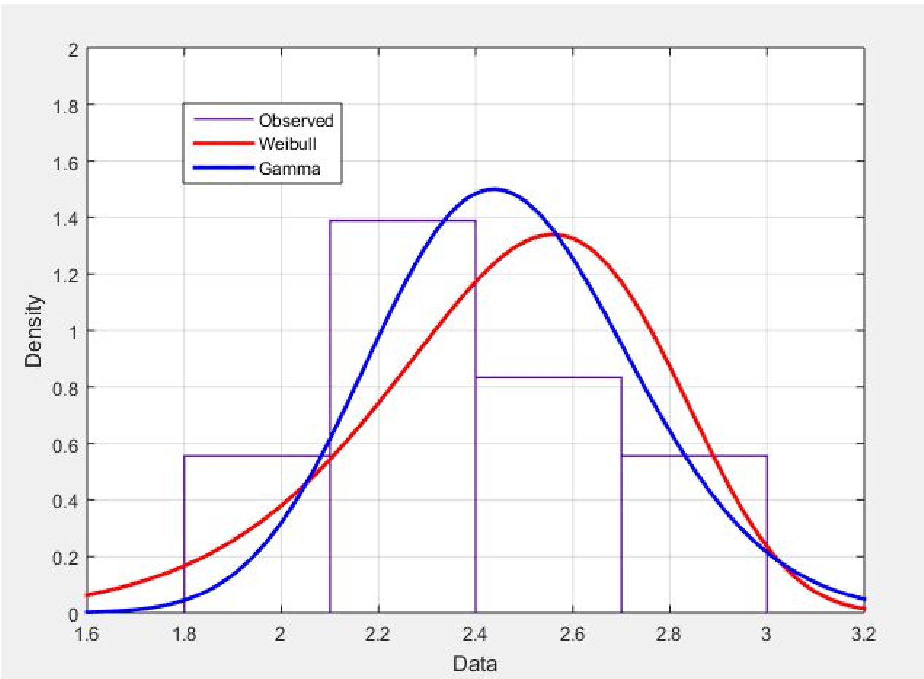

Figure 154: PDF-Güzelyurt-2013

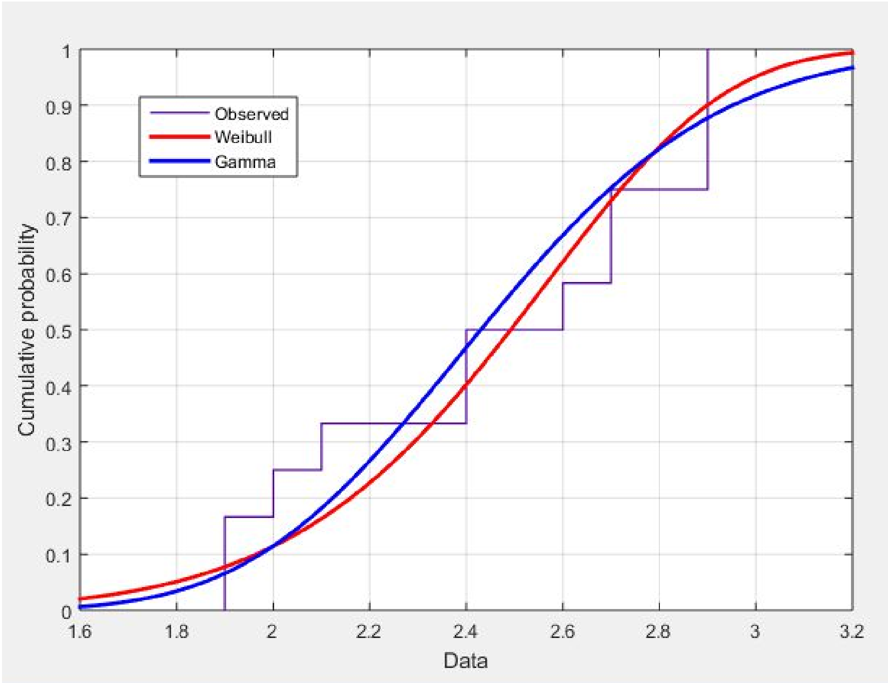

Figure 155: CDF-Güzelyurt-2014

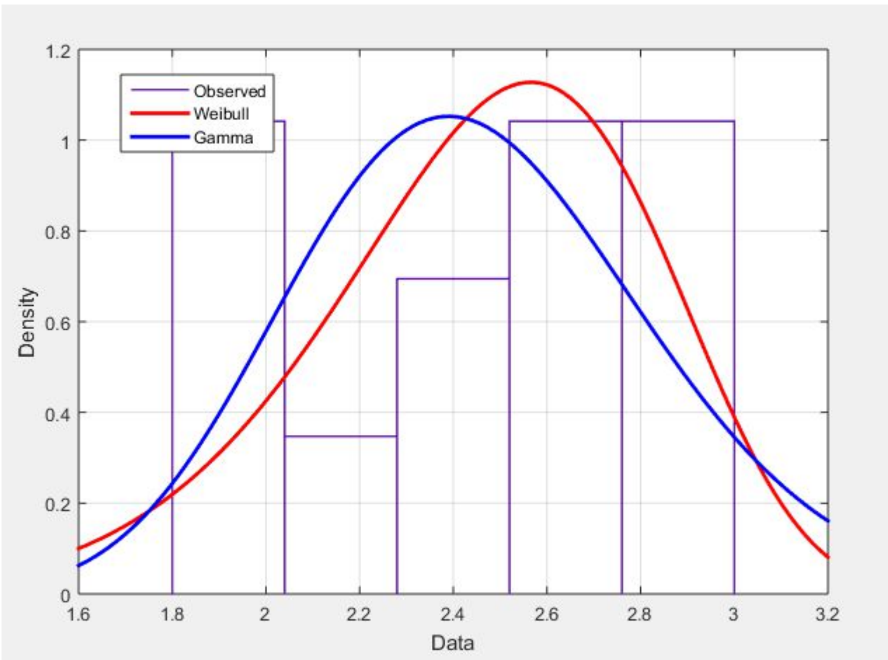

Figure 156: PDF-Güzelyurt-2014

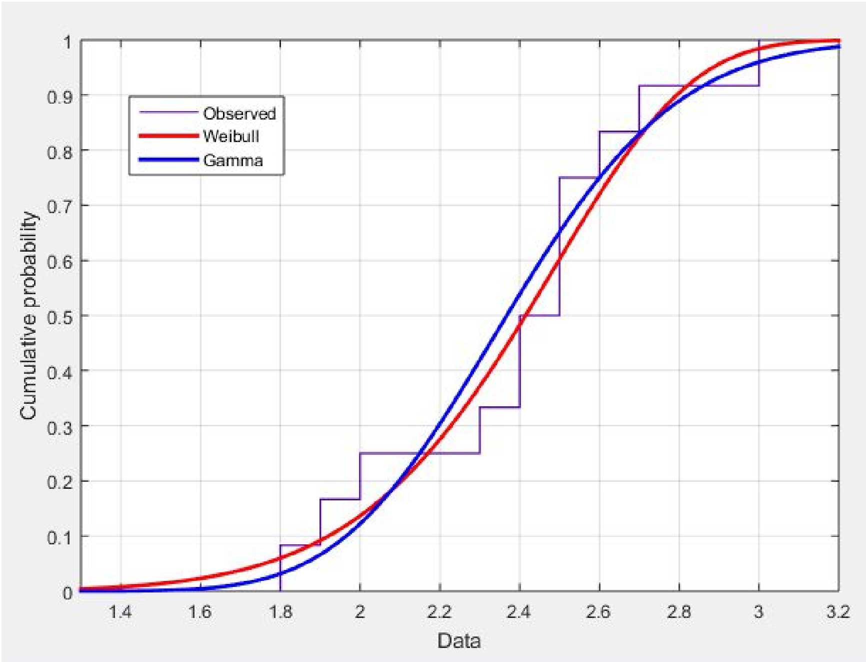

Figure 157: CDF-Güzelyurt-2015

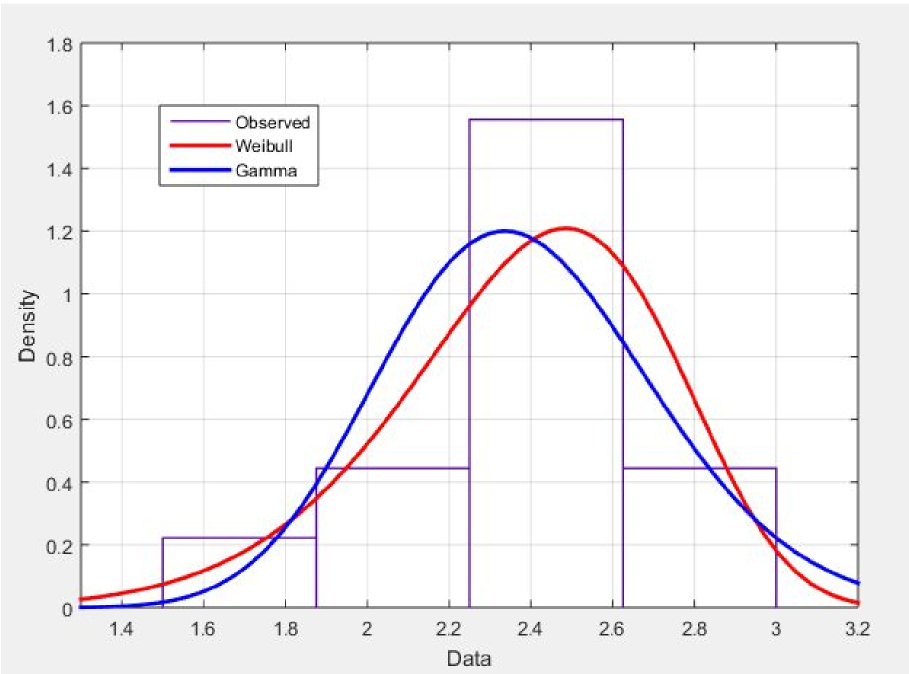

Figure 158: PDF-Güzelyurt-2015

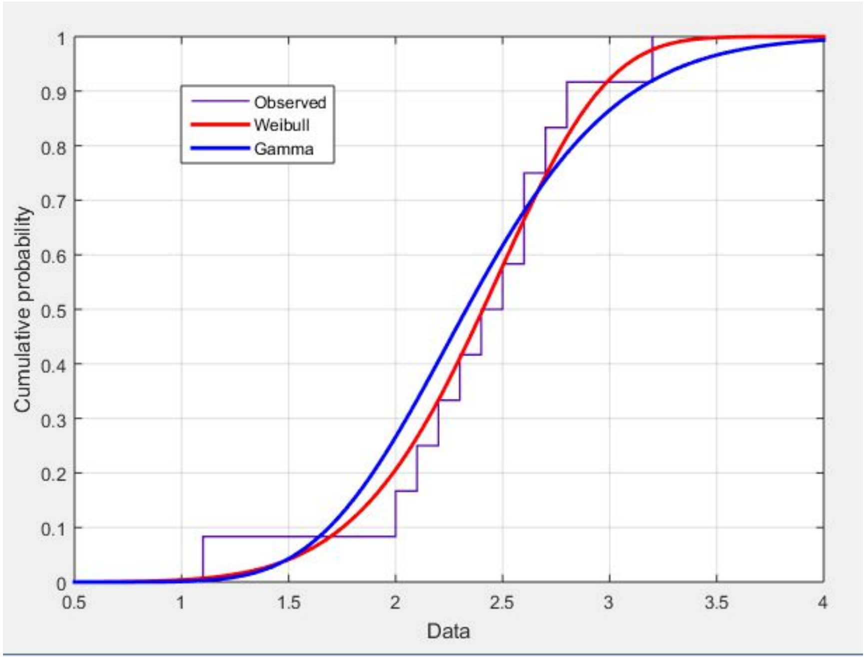

Figure 159: CDF-Güzelyurt-2016

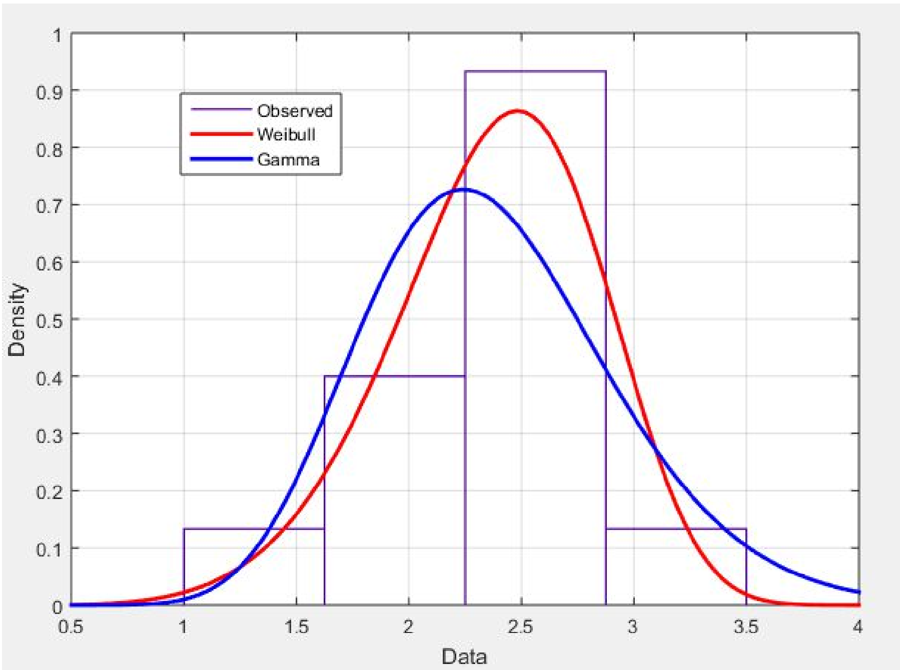

Figure 160: PDF-Güzelyurt-2016

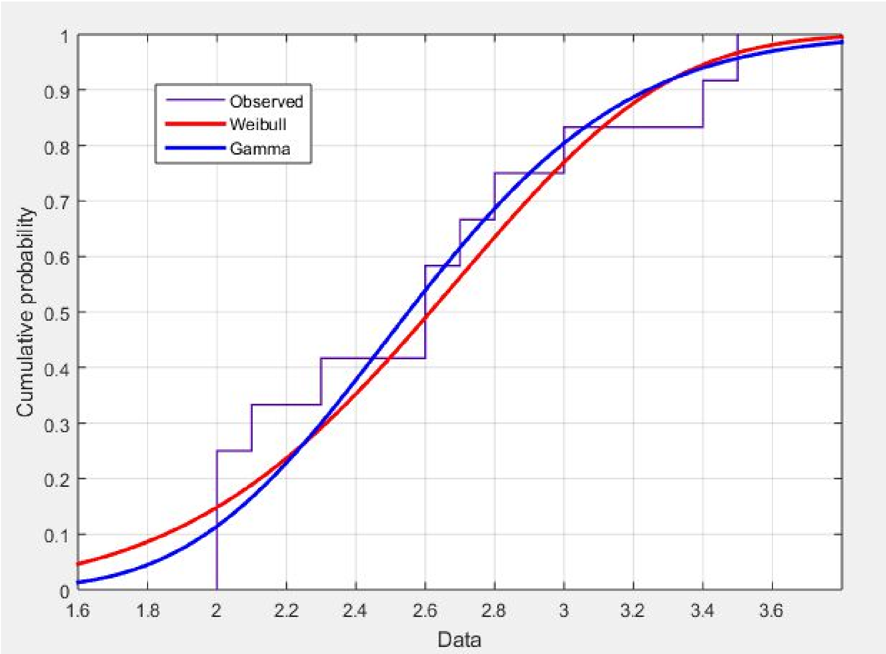

Figure 161: CDF-Lefkoşa-2009

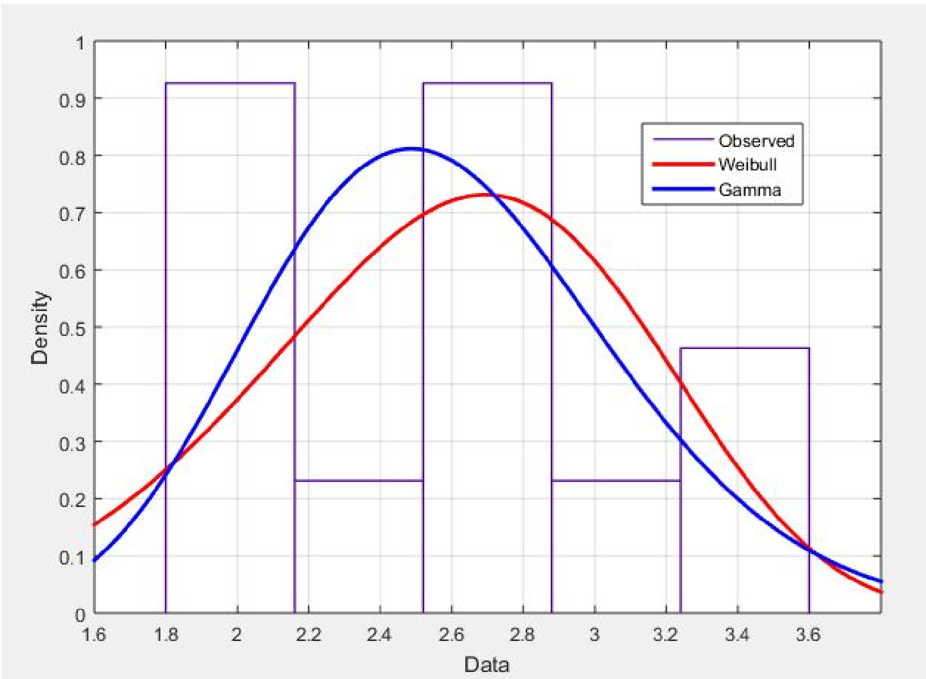

Figure 162: PDF- Lefkoşa -2009

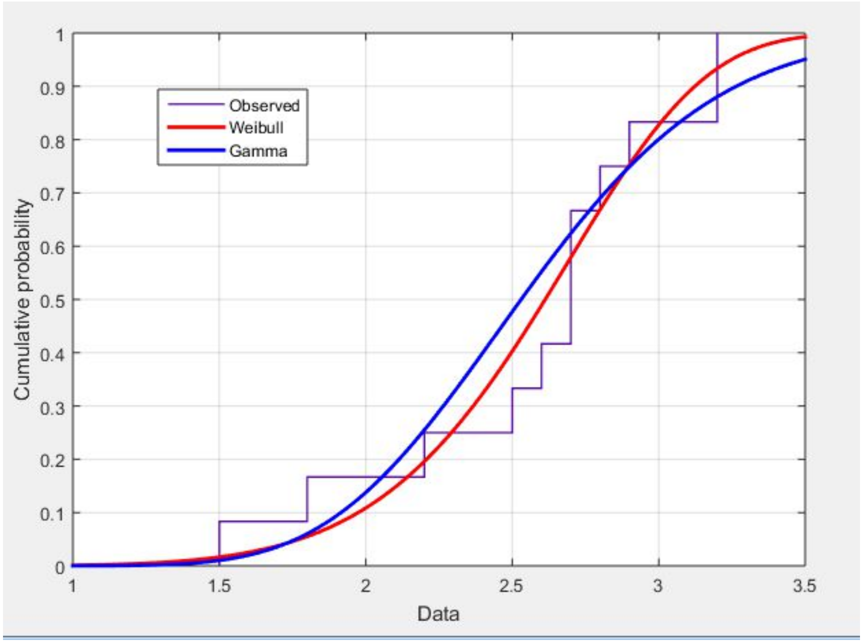

Figure 163: CDF- Lefkoşa -2010

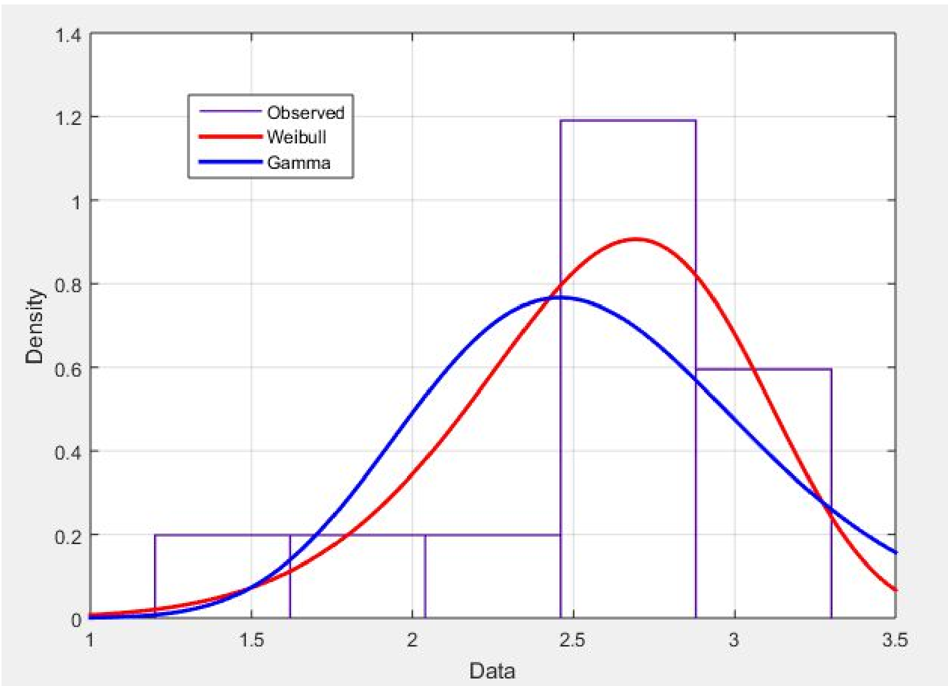

Figure 164: PDF- Lefkoşa -2010

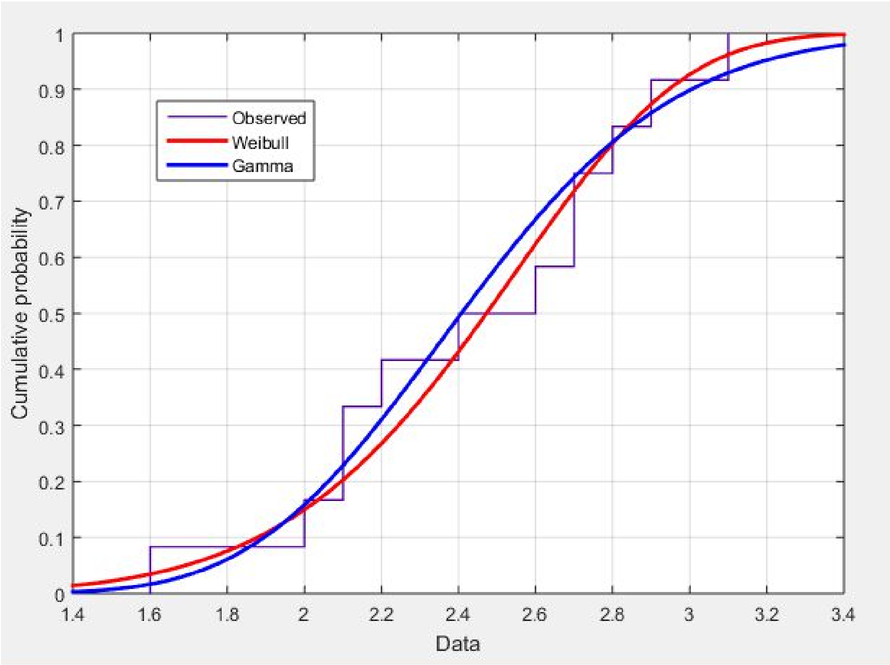

Figure 165: CDF- Lefkoşa -2011

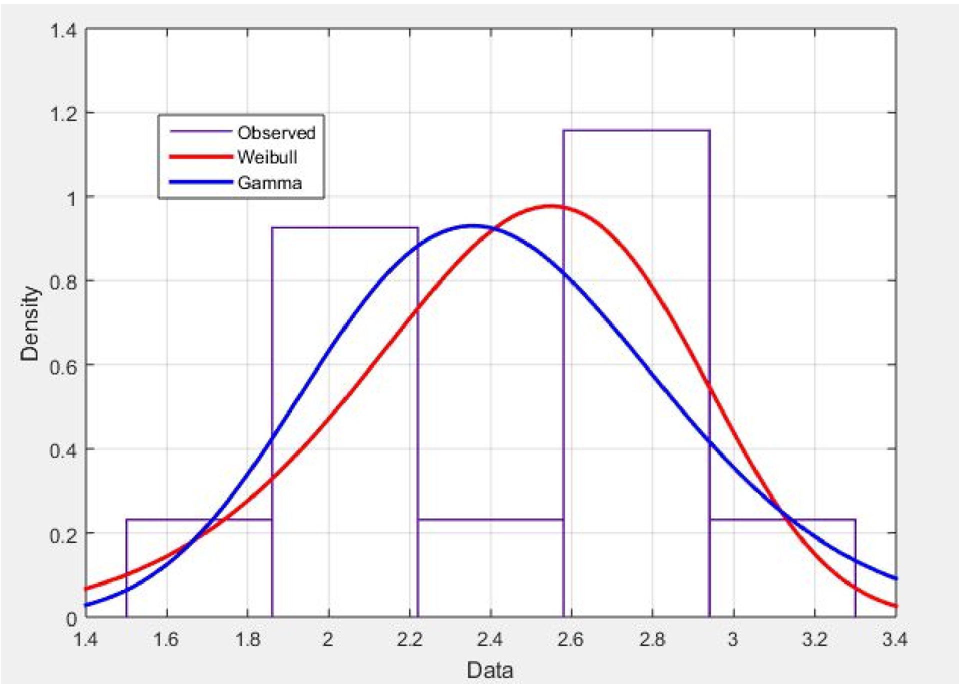

Figure 166: PDF- Lefkoşa -2011

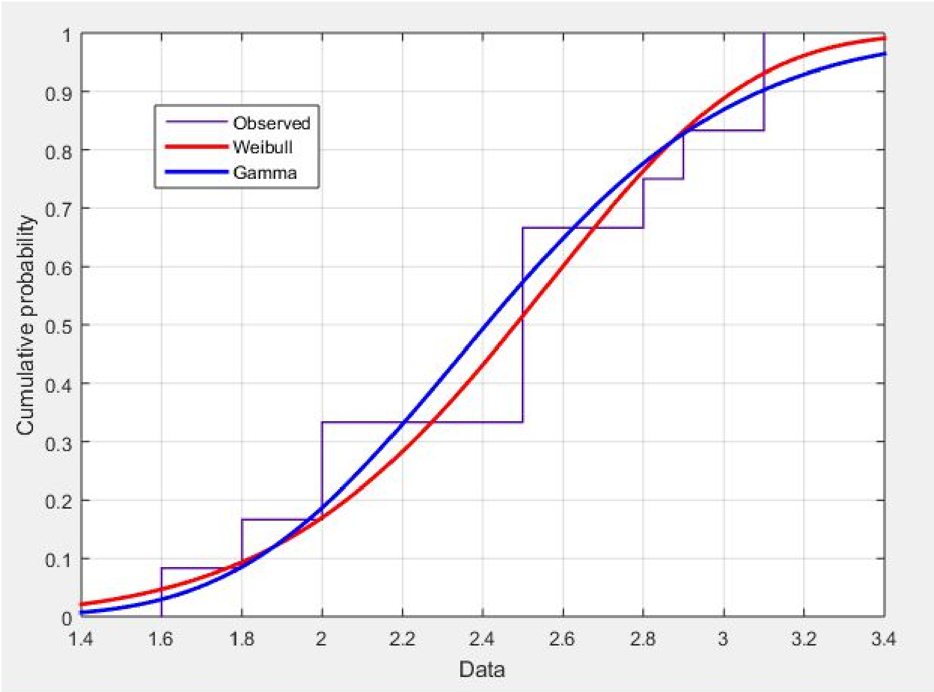

Figure 167: CDF- Lefkoşa -2012

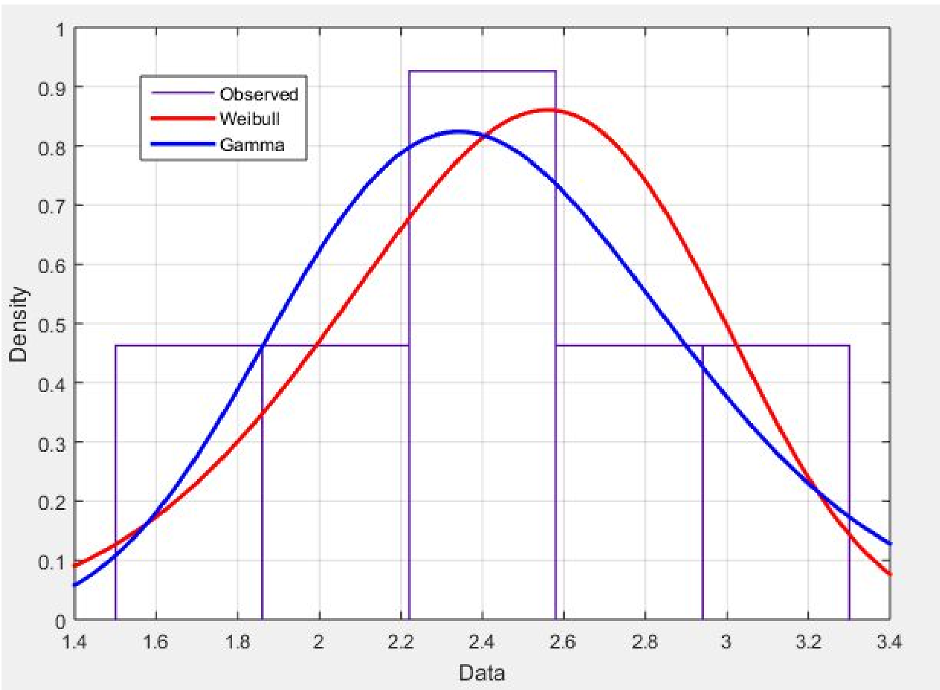

Figure 168: PDF- Lefkoşa -2012

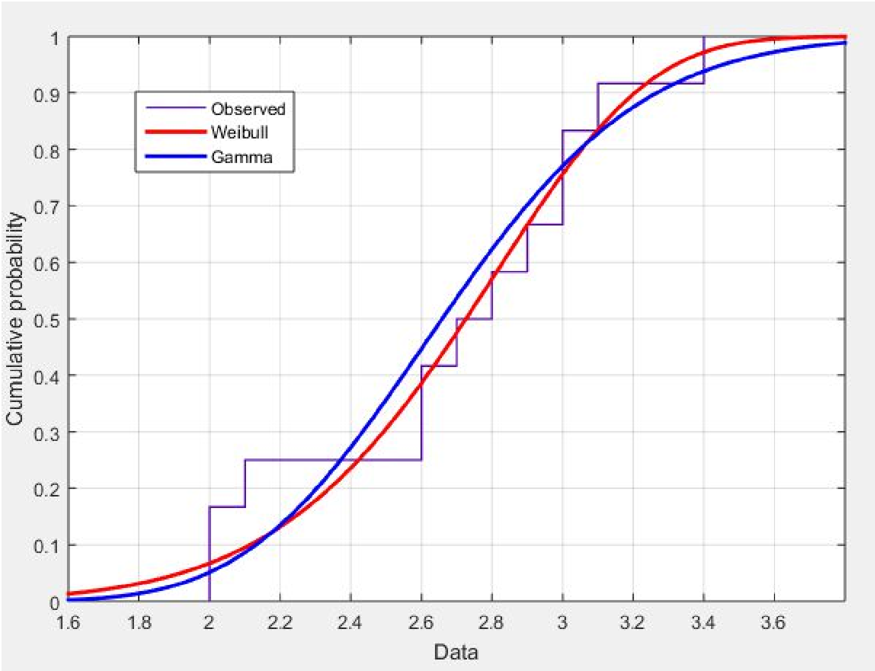

Figure 169: CDF- Lefkoşa -2013

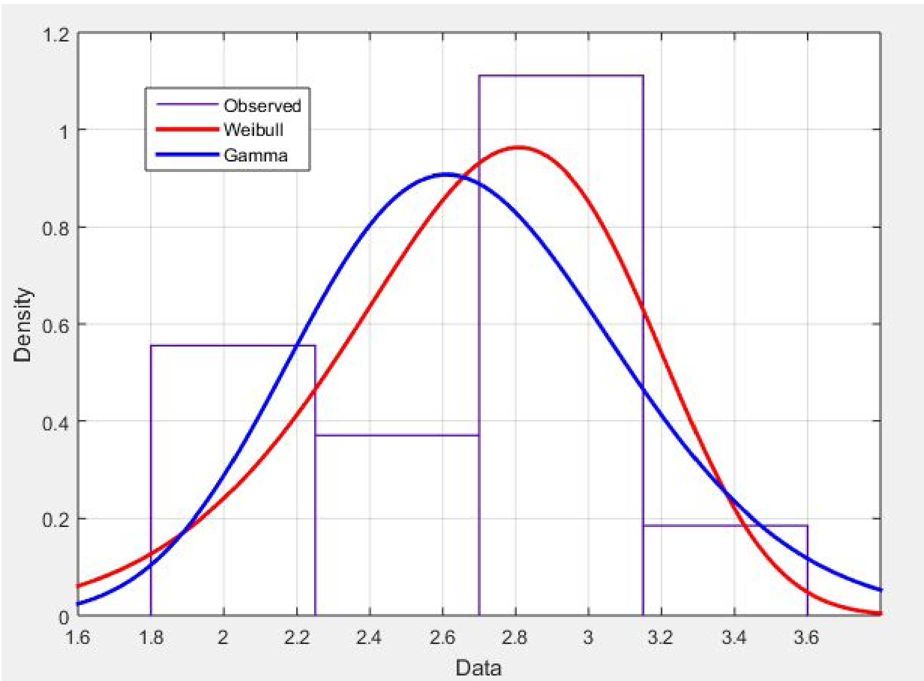

Figure 170: PDF- Lefkoşa -2013

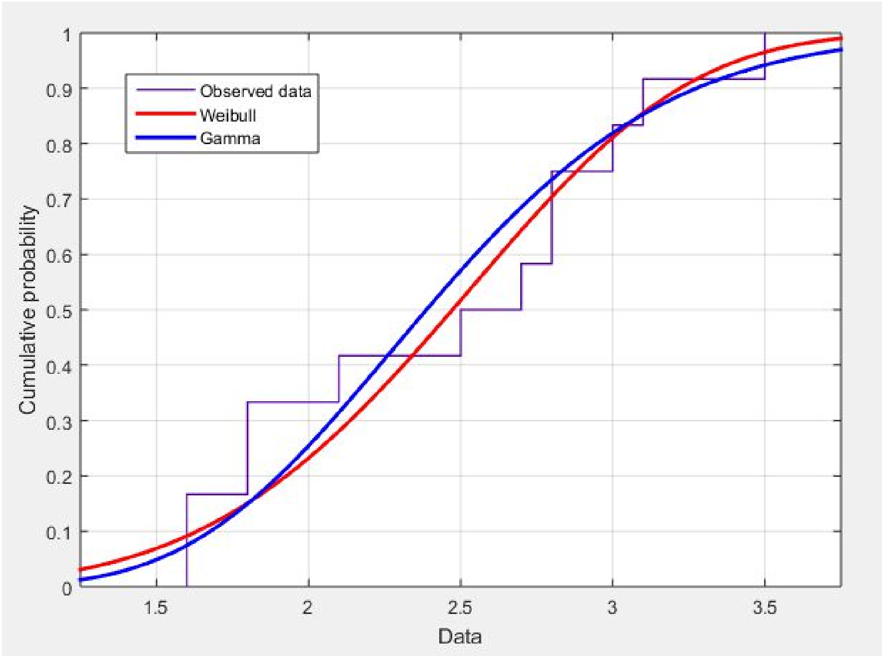

Figure 171: CDF- Lefkoşa -2014

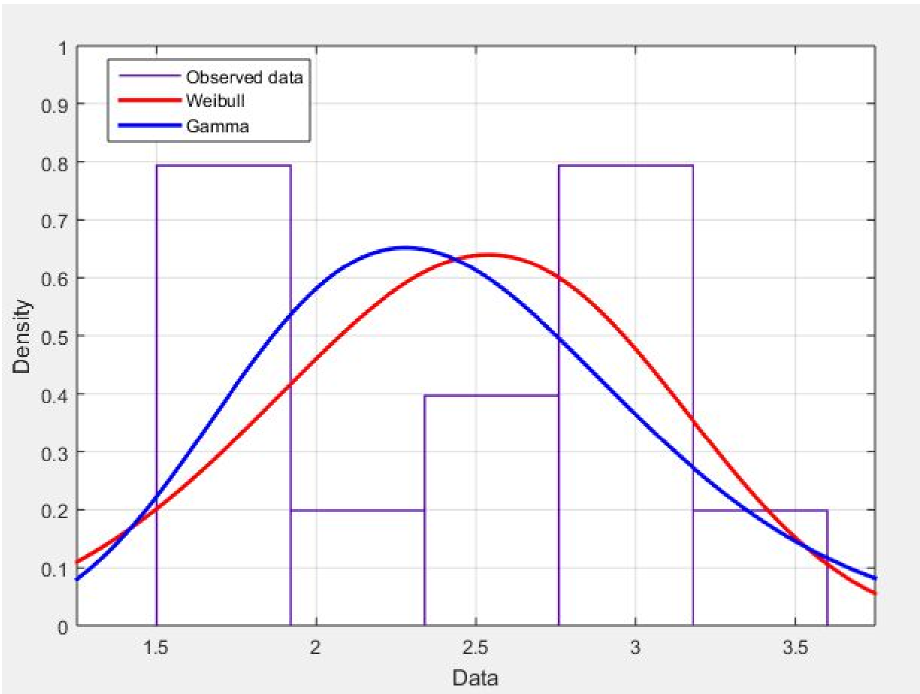

Figure 172: PDF- Lefkoşa -2014

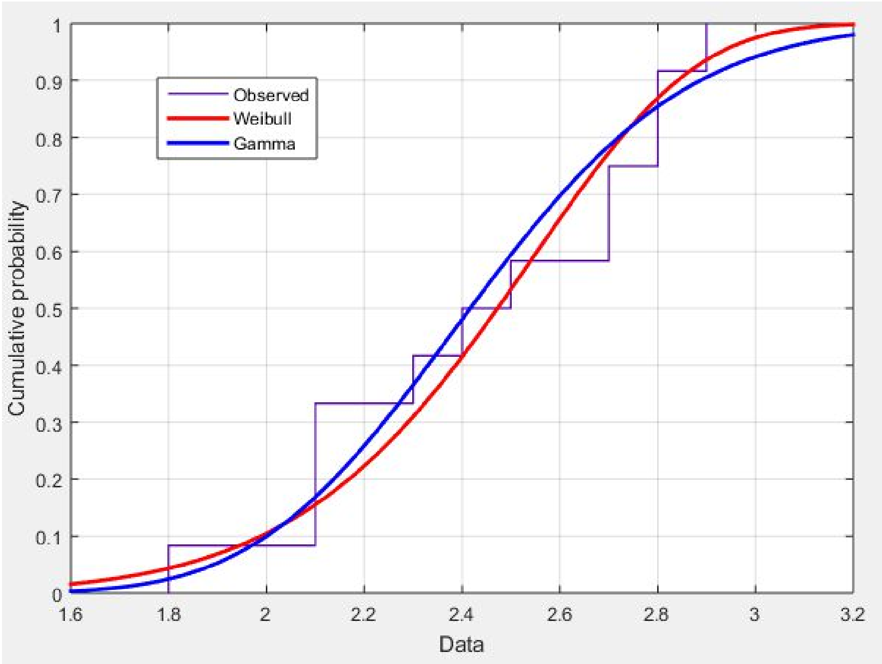

Figure 173: CDF- Lefkoşa -2015

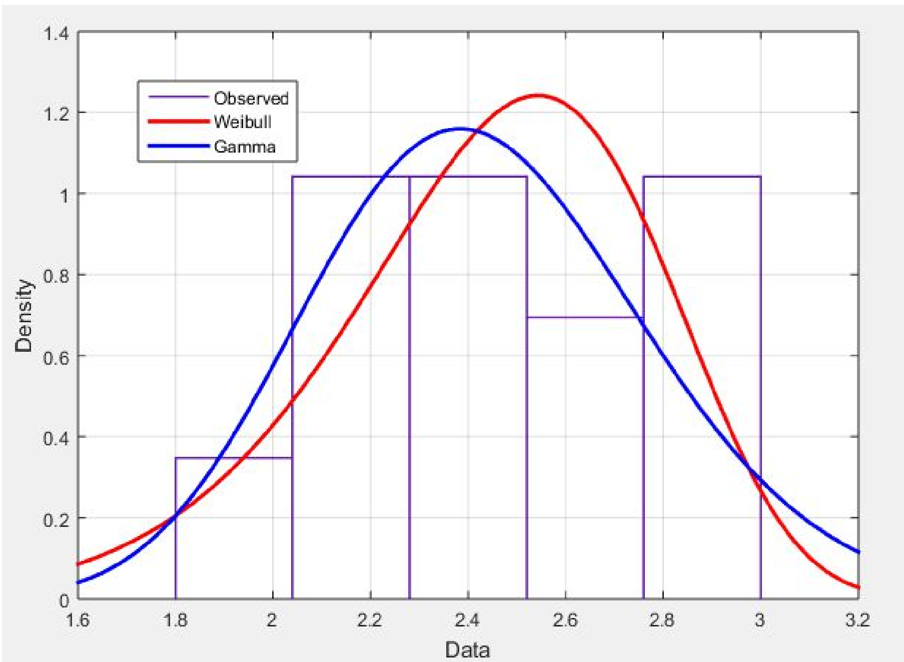

Figure 174: PDF- Lefkoşa -2015

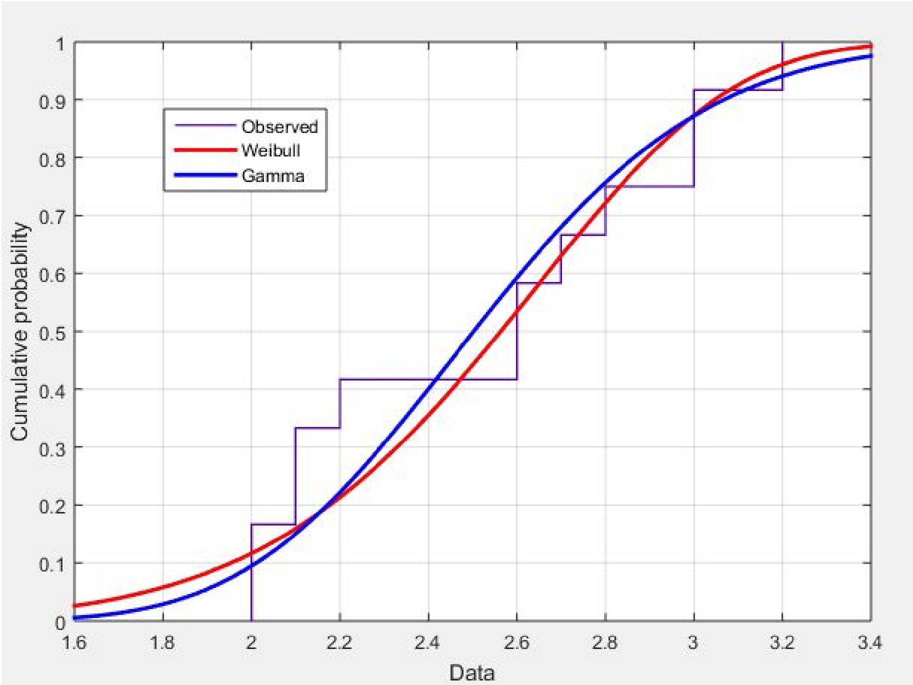

Figure 175: CDF- Lefkoşa -2016

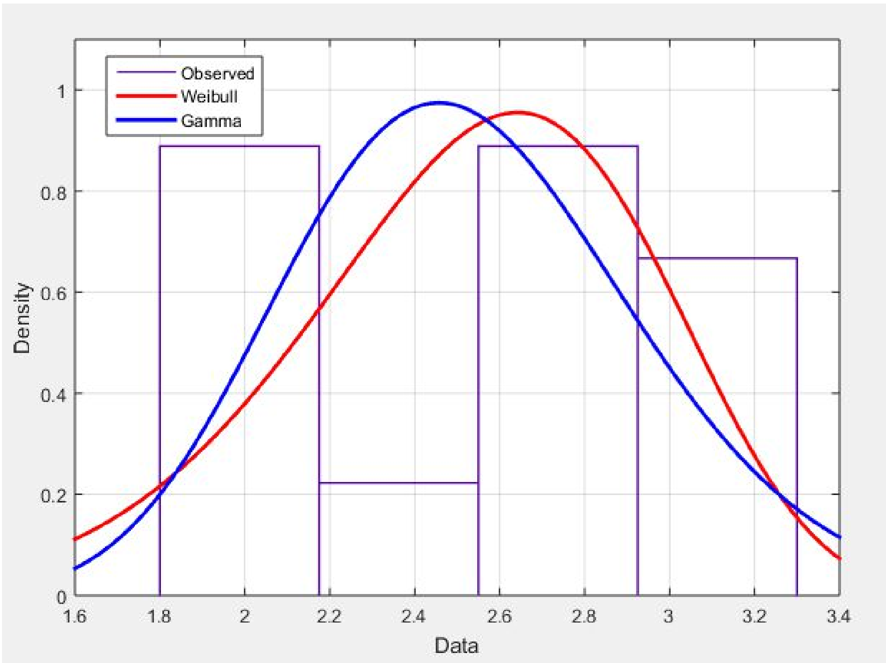

Figure 176: PDF- Lefkoşa -2016