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Statistical Analysis of the Wind Resources at the Importance for Energy Production in Bangladesh

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Abstract

Wind is an important source of renewable energy. Bangladesh being a tropical country which has a lot of wind flow at different seasons of the year. In this paper, wind power system with battery storage will be presented that can play electricity to our daily uses. Rayleigh distribution functions were considered and fitted to estimate of wind speed data. In our study, we studied previously collected data on the wind resources available in Bangladesh and by analyzing this data and have necessary accessory for application like wind power generation. The wind resources were mapped with the wind power density and the annual mean wind power estimated at, 194.2556W/m² and 2351.76 Kh and the annual mean wind speed 2.34635 kph on 50m heights and RCL = 0.

Keywords: *Rayleigh Probability Density, wind speed, wind energy*

1. Introduction

The assessment of the wind resources at a given site is one of the preliminary steps in the sitting of a wind farm project. The assessment of the wind resources involves analyzing in detail the wind profile at a given height such as the wind speed and its prevailing direction, turbulence intensity, the shape and scale parameters, the wind distribution, wind power density and class etc. At a given site, a known wind power class is regarded as one of the approaches for assessing the wind resource of a given site. To determine the suitability of this site for wind energy generation; the mean wind speed, the shape and scale parameters of the site are estimated. The optimistic height from the ground is 40-70m, where the wind speed is high which is more applicable for wind energy generation [1]. The estimated shape and scale parameters are used alongside with the various statistical functions to model the wind speed, and the wind distributions which best describe the variation of the wind at the site are obtained. Once the wind distributions are obtained evaluation of the wind resources is conducted based on the known wind distribution for accurate sizing of the wind energy systems. The developed site wind power density is used to analyze the availability of wind energy generation for a known wind speed.

A number of studies have been conducted on the uses of probability density function for modeling of the wind speed around the world. Some of these density functions include Weibull, Rayleigh, Gamma, Lognormal, Exponential, and Gaussian *etc.*,2-5]. The Weibull function is widely used in the wind industry as the preferred approach for modeling of the wind speed for energy assessment due to its wide range of versatility, flexibility, and usefulness for describing the wind speed variation. It applicability can also be found in reliability engineering and life data analysis. Some authors, [6-8] suggested the Weibull distribution function as the best for modeling the wind speed at any site. In other research the wind speed data is efficiently fitted in Rayleigh probability distribution function [9]. So for

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our study we will estimate the wind speed and energy generation from wind speed using Rayleigh function which is more and more applicable in the situation of 50m high air speed calculation belong to Bangladesh wind force data [9].

2. Wind Prospect in Bangladesh

Bangladesh is situated in the latitude between $20^0 34^/$-$26^0 38^/$N and longitude between 88^0-92^0E. The country has a 724km long coastal ling long the Bay of Bengal, which belongs to Bangladesh. The wind blows over Bangladesh from March to September with a monthly average 3m/s to 6m/s [10]. The peak wind speed occurs during the months of June to July [10]. Park of wind turbines in coastal areas, can be incorporated in electricity grid on a substantial basis and could add reliability and consistency to the electricity generated by the Kaptai Hydro-electric power Station from March to September, during which load shedding becomes critical than winter season.

3. Wind Data in Bangladesh

The wind data Jan 2002 to Dec 2013 were selected at Dhaka Airport weather stations on a hub height 50m above ground level as shown in table 1. This time series wind data were continuously measured by the wind acquisition systems deployed on a measurement at this weather station. The wind data collected include the mean wind speed and direction, temperature, atmospheric pressure and air humidity. Here is shown the relationship between the wind availability and the speed of wind appendix Figure 1. From the Table 1 we see that the availability of wind is positively related with wind speed observed [11].

The wind speed varies continuously as a function of time and height and its assessing the wind resources potential of the locations. For longitudinal wind speed data we see that the wind speed of data is decreased gradually for different years. Most of the time the wind speed is high at month April – May and in year 2002-2005 is higher than others. We can conclude that from the data, the wind speed is decreasing day by day and change the weather belonging summer seasons.

4. Modeling

The wind speed variation at a given site is usually described by the wind density. Around the world, to identify the suitable statistical distribution for describing the wind speed variation, the following functions are been used and they include the Weibull [12], Rayleigh [13], Gamma [8, 14], Lognormal [15], Logistic [16-18] *etc*. However, the Weibull and Rayleigh functions are the widely accepted and extensively used statistical models for wind energy application. In this study, we consider the Rayleigh function because this function is a special case of the Weibull function. This function is found to typically model the wind speed at some sites where the Weibull function could not accurately modeled. At our wind site, where the value of k is 2, is commonly referred to as the Rayleigh function well fitted. At a wind site where the Weibull function is a poor model for fitting the wind speed, it may be appropriate to model the wind speed with a Rayleigh function [19].

4.1. Rayleigh Probability Density

Putting the value k = 2 into the probability distribution function of Weibull distribution of a continuous distribution is defined as Rayleigh distribution and is $f_v = \frac{2v}{c^2}\exp[-(^{v}/_{c})^2]$ Where c is the scale parameter at k = 2 and f_v is the Rayleigh probability density function.

And the cumulative density function is defined as $F_v = 1 - \exp[-(^{v}/_{c})^2]$

The Rayleigh scale parameter C_r is obtained using the maximum likelihood estimator as expressed in the given equation [20] $C_r = \sqrt{\frac{1}{2N}\sum_{i=1}^{N} v_i{}^2}$ Where C_r is the Rayleigh scale parameter and v_i is the wind speed observation at i^{th} time.

The mean of the Rayleigh distribution is defined by [19-20] $\bar{v} = C_r\sqrt{\frac{\pi}{2}}$ (1) Where $\bar{v}$ is the mean of the distribution functions. From the above Fig2 we see that the fitted Rayleigh average speed of wind is always positively correlated (r = 0.99999146) with the actual wind speed and for chi square test (χ^2 =0.999455) is significant (at 0.05 level of significance). So for our study, Rayliegh function is approximately well fitted for our wind site data.

4.2. Estimation of Wind Power Density

The available wind power per unit swept are known as wind power density (W/m^2) is defined as

$P = \frac{1}{2}\rho(h)V^3$, Where V is the observed wind speed, $\rho(h)$ is the varied air density sweeping the rotor blades, and P is the wind power density. The theoretical maximum power {W} of wind that flows across the rotor swept are A at a given speed V is given by $P_0 = \frac{1}{2}\rho(h)AV^3$

Where A is the swept area and P_0 is the theoretical wind power.

The mechanical power of the wind turbine is defined as $P_m = C_p\,\frac{1}{2}\rho(h)AV^3$

Where P_m and C_p are the mechanical power developed by the rotor blades and the power coefficient of the rotor, respectively. Based on the bertz law, the maximum wind power that can be extracted at any given time is 59% but in the practical design of the rotor blades, the maximum Cp values range from 0.2 to 0.4 [21]. The electrical power outputs {W} of the wind generator is defined as $P_e(v) = \eta_{R,G} * P_m$ Where η is the efficiency of the gearbox and electrical generator which is always estimated or specified and $P_e(v)$ is the electrical power of the wind generator.

4.3. Actual Power Density

In this study the actual wind power density used in the study is estimate using below equation, the speed is obtained using the actual wind distribution, *i.e.*, $v^3 = \int_0^\infty v^3 f(v)dv$. Using this the actual power generation is $P_A = \frac{1}{2}\rho(h)\int_0^\infty v^3 f(v)dv$, Where $f(v)$ the actual wind distribution and P_A is is the actual wind power density.

4.4. Rayleigh Power Density

The Rayleigh wind power density P_R is estimated using the given equation below [24]

$P_R = \frac{3}{\pi}\rho(h)(\bar{v})^3$

From the above equation (1), putting k = 2 $\bar{v} = C_r\,\Gamma(1 + .5) = C_r\,\Gamma(1.5) = C_r\sqrt{\frac{\pi}{4}} = 0.88662 * C_r$

Where $\bar{v}$ is the Rayleigh mean wind speed for k = 2, c is the Rayleigh scale parameter and P_R is the wind power density, and density is redefined as $P_{R\,(wind)} = \frac{3c}{\pi}\rho(h)\sqrt{\frac{\pi}{4}}$

5. Result and Discussion

The wind power potential at a given location is usually classified according to its wind power class. The wind power class of any given site ranges between classes 1 to 7 depending on the prevailing wind resources. A typically 10-40meters WPD estimates are suitable for small to medium scale wind energy system while a 50-meter WPD estimates are the industry standard metric used to gauge the site wind resource for large-scale wind energy systems. The criterion for the selection of the hub height(s) for the energy system depends mainly on the site wind resources and the associated capital cost. The wind resources at this site are mapped with the wind power density and the summary of the monthly mean wind power densities estimated at this site are shown.

From the Figure 1 and Table 1 we see that maximum wind density and power is extracted in month April to May in 2012-Dec 13 and wind power generation is 287.575W/m^2 in Dhaka airport stations and on an average $P_{R\,(wind)} = 699.32$ Watt. Then the power that can be extracted from wind assuming 25% turbine efficiency is $P_{turbine} = 0.25 \times 699.32 = 174.84\, watts$

Year	Average Wind Speed	Average Cr	Wind Power $P_R = \frac{3c}{\pi}\rho(h)\sqrt{\frac{\pi}{4}}$ W/m^2
2002-2005	4.535833	3.2073	721.39
2005-2008	4.0625	2.8726	705.55
2012-2013	2.6525	1.873333	699.32

Similarly we can estimate the optimum power of different stations in Bangladesh is Muhuri Dam, Feni 381.83 watt, Mognamaghat Cox's Bazar 456.75 watt, Parky Saikat Patenga 422.87 watt, Kuakata Patuakhali is 424.38 watt. And 25% turbine efficiency, then the usable energy in Muhuri Dam, Fenis 95.45 watt, Cox's Bazar 114.19 watt, Parky Saikat Patenga 105.72 watt,Kuakata Patuakhali is 106.09 wat. Total 592.29 watt. So on an average per station the potential energy is produced 119.258 watt.

Assuming that all wind installation is alone and total wind turbine is 19720 shows in table app2. So total wind power is generated in Bangladesh is approximately 2351.76 Kwatt.

6. Cost Analysis

From the analysis of different studies it is found that the price for producing per unit electricity from municipal solid waste by incineration would be between taka 9.50-10.50 (USD 0.136-0.150/unit) [27]. Where in Bangladesh, it is found that the electricity production cost for each unit of electricity from wind based power plant could be around taka 10.00-12.00 (USD 0.142-0.171/unit), from diesel fired power plants is taka 8.00-14.00 (USD 0.114-0.200/unit) and Taka 8.00 (USD 0.114/unit) from furnace fired power units [28,29]

7. Conclusion

In this study assessments of wind characteristics for coastal region of Bangladesh ware made the following conclusion can be drawn

1. The shape factor k = 2 and scale factor are determined for each month and it is found by Rayleigh functions is on an average 1.873333 which remains between 1.1 to 2.2.
2. The mean wind speed for each location is on an average is observed 2.6525kph and using Rayleigh function is estimated 1.873333kph which is less error.
3. Total estimated energy by wind turbine system is 2351.76 KWh.

It can be an excellent, cost effective and also a reliable solution to mitigate the existing power crisis if we can implement the installation of more wind turbine in rural area as well as urban area in Bangladesh. It has a great impact on improving the socio-economic condition of rural people as well as will be a good sign of green energy technology.

Table 1. Wind Speed (kph) data and Data Availability (%) from Dhaka Airport weather stations at 2002-13

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan-02 Dec 05	2.91	3.52	5.55	7.22	6.91	6.21	6.52	4.91	3.64	3.02	1.71	2.31
Availability (%)	85	73	82	81	82	55	92	86	91	89	85	82
Jan 05 Dec 08	2.62	3.31	4.71	6.31	5.82	5.71	5.81	4.41	3.61	2.61	1.92	1.91
Availability (%)	87	82	86	86	79	66	87	88	88	88	90	82
Jna12-Dec 13	1.91	2.52	2.91	4.15	3.71	3.24	1.91	4.21	2.65	2.41	1.12	1.09
Availability (%)	64	66	82	90	93	81	77	82	86	62	90	74

Average value (January 2012 – December 2013): 2.6Kph (Sources DAWS, 2012 -13)

Table 2. Estimation of the scale parameter and average wind speed by using Rayleigh probability distribution function at January 2012 – December 2013 data [11]

Month	Wind speed	Scale parameter C_r	Density fun f_v	Average wind speed $\bar{v}$
January	1.91	1.35	0.283184	1.690875
February	2.52	1.78	0.214357	2.22945
March	2.91	2.05	0.184631	2.567625
April	4.15	2.93	0.130043	3.669825
May	3.71	2.62	0.145539	3.28155
June	3.24	2.29	0.166931	2.868225
July	1.91	1.35	0.283184	1.690875
August	4.21	2.97	0.127985	3.719925
September	2.65	1.87	0.083441	2.342175
October	2.41	1.71	0.126163	2.141775
November	1.12	0.79	0.08094	0.989475
December	1.09	0.77	0.09568	0.964425
Average	**2.6525**	**1.873333**	**0.160173**	**2.34635**

Table 3. Estimation of Mean Square Error

Month	Wind speed	Average wind speed $\bar{v}$	Mean Square Error
January	1.91	1.690875	0.048016
February	2.52	2.22945	0.084419
March	2.91	2.567625	0.117221
April	4.15	3.669825	0.230568
May	3.71	3.28155	0.183569
June	3.24	2.868225	0.138217
July	1.91	1.690875	0.048016
August	4.21	3.719925	0.240174
September	2.65	2.342175	0.094756
October	2.41	2.141775	0.071945
November	1.12	0.989475	0.017037
December	1.09	0.964425	0.015769

Table 4. Monthly Mean Wind Power Densities and its errors at Jan 2012-Dec 2013

Month	Wind speed	Scale parameter C_r	Wind Power $P_R = \frac{3c}{\pi}\rho(h)\sqrt{\frac{\pi}{4}}$ W/m^2	Mean Square Error
January	1.91	1.35	139.9884	0.048016
February	2.52	1.78	184.5774	0.084419
March	2.91	2.05	212.575	0.117221
April	4.15	2.93	303.8268	0.230568
May	3.71	2.62	271.6813	0.183569
June	3.24	2.29	237.4619	0.138217
july	1.91	1.35	139.9884	0.048016
August	4.21	2.97	307.9746	0.240174
September	2.65	1.87	193.9099	0.094756
October	2.41	1.71	177.3187	0.071945
November	1.12	0.79	81.91916	0.017037
December	1.09	0.77	79.84526	0.015769
Average	2.6525	1.873333	194.2556	0.103474

Table5: Average wind Speed (Kph) in Bangladesh in different stations is given (H=50m, RCL=0) [11]

	Muhuri Dam, Feni	Mognamaghat Cox's Bazar	Parky Saikat Patenga, Chittagong	Kuakata Patuakhali
Annual Average Wind Speed	1.805	1.946	1.868	1.871

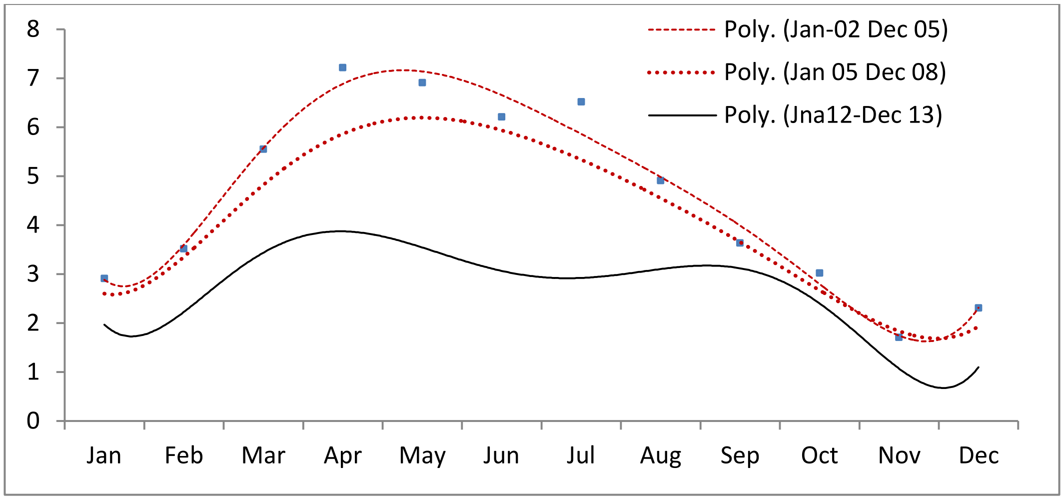

Figure 1. Comparison of the Monthly Mean Wind Speed Variation in Dhaka Airport Station, Bangladesh

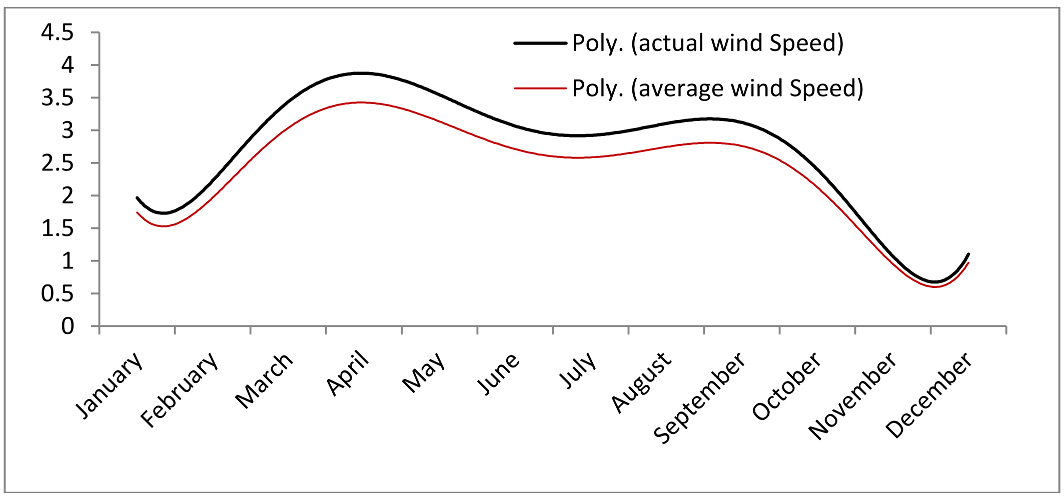

Figure 2. Comparison between Fitted and Actual Wind Speed

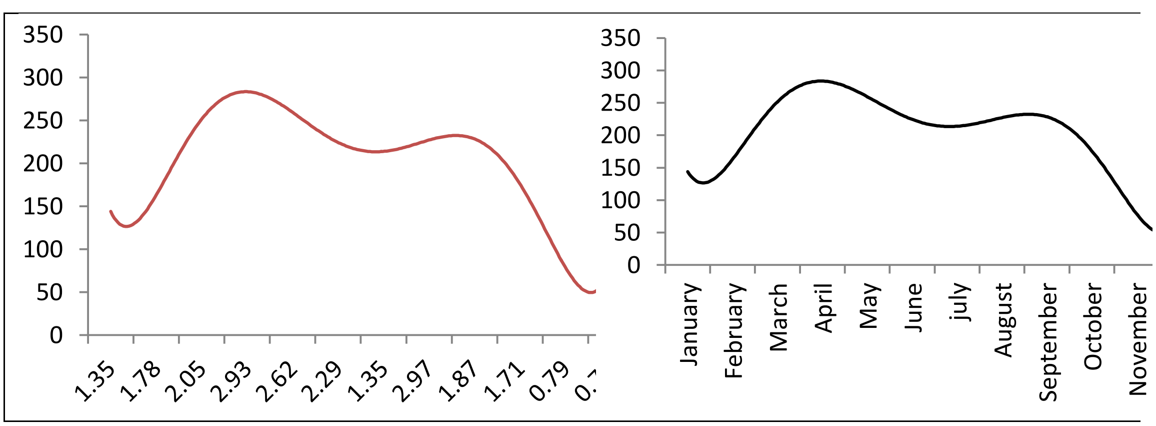

Figure 3. Power Generation for Different Scale Parameter and Month Of the Year

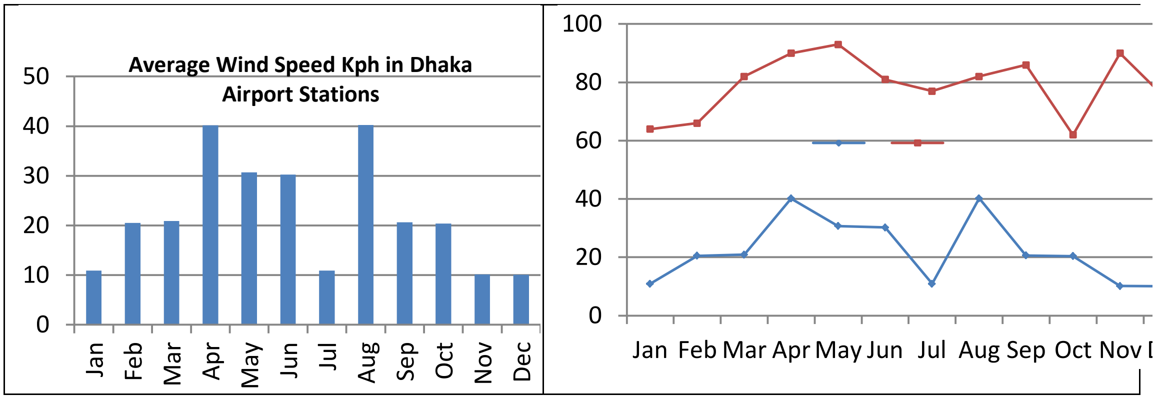

Figure app1. Comparison of the monthly mean wind speed variation and data availability% in Dhaka airport station, Bangladesh for the year January 2012-December 2013

Table app2: Wind turbine installations in Bangladesh by different Organization [27]

name	Type of Application	Installed Capacity(Watt)	Location	Present Status
Grameen Shakti	3 Hybrid	4,500	Grameen Offices in the Coastal Region	Functioning
	Hybrid	7,500	Cyclone Shelter in the Coastal Region	Functioning
BRAC	Stand-alone	900	Coastal Region	Functioning
	Hybrid	4,320	Coastal Region	Functioning
Bangladesh Army	Stand-alone	400	Chittagong Hill Tracts	Functioning
IFDR	Stand-alone	1,100	Teknaf	Functioning
	Stand-alone	600	Meghnaghat	Functioning
LGED	Wind-PV Hybrid	400	Kuakata	Functioning
Total		**19,720**		

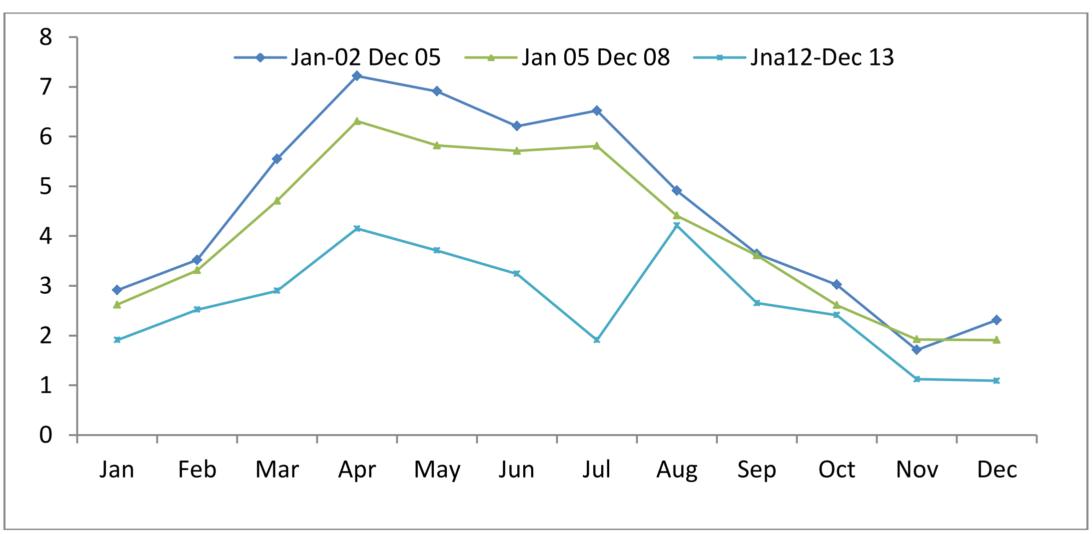

Figure app2. Wind Speed in Different Months in Different Years

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