CONNECTION BETWEEN THE POTENTIAL WIND ENERGY AND THE WINDY DAYS

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Abstract

Preliminary wind climate information are required for the selection of the sites of energetic wind measurements. Optimal locations of wind energy projects, where the amount of utilizable wind energy can be forecasted with a good approach, can be determined using GIS and statistical methods. Anyhow, it is necessary to elaborate methods what make posible to gain data for the wind potential of a given location on the base of measured data. Monthly number of windy days can be such predictor if its basic statistical parameters and its connection to the monthly mean wind power can be determined. This latter one can be substituted by the area under the curve of the function fitted to the hourly averages of the cubes of the wind speeds. A regression modell is fitted to the monthly number of windy days and areas under the curve, on the base of time series of 7 Hungarian weather stations and the error of the modell is determined. On this base, the modell is extrapolated to a 35 years long period. The area under the curve proportional to the monthly mean wind power calculated on the base of the monthly number of windy days show a significant decreasing trend in 4 Hungarian weather stations.

Keywords: statistics of windy day, specific wind power, regression model, error and extrapolation of the regression model

1. Introduction

In Western European countries that have prosperous wind potential, due to the oil crisis in the 70's a huge research and development surge commenced in the field of wind energy utilization. After the meteorological studies and establishment of technical and mechanic background of applicable instruments a new technical innovation has commenced that influence is undisputed in the next forty years in both scientific and economic aspects.

The basic stipulations of wind energy utilization as well as in case of all other renewable energy sources are the proper natural capabilities. Nevertheless, comprehensive utilization and spread can be made through social-economic-political-ecological agreement only. Utilization of renewable energies depends on historical, economical and political background, costumer's structure of the given area beyond natural environments.

From the aspect of domestic spread of renewable energy utilization it is not negligible that to what degree are renewable energies accepted and known by the people. The population of areas involved must be aware of consequences and impacts of utilizations. On the other hand the attitude of the local population can be used as a respond towards various decision making levels – first of all for the central government. This could help in process of better subsidization system establishment.

The aim of our studies in the Cserehát micro-region was to answer the before mentioned question (Pénzes et al. 2005). On the basis of our questionnaire surveys among the renewable options in the close proximity of people's residence the highest approval and support level is for those instruments that are related to wind and solar energy utilization. This result is indicated on Fig. 1.

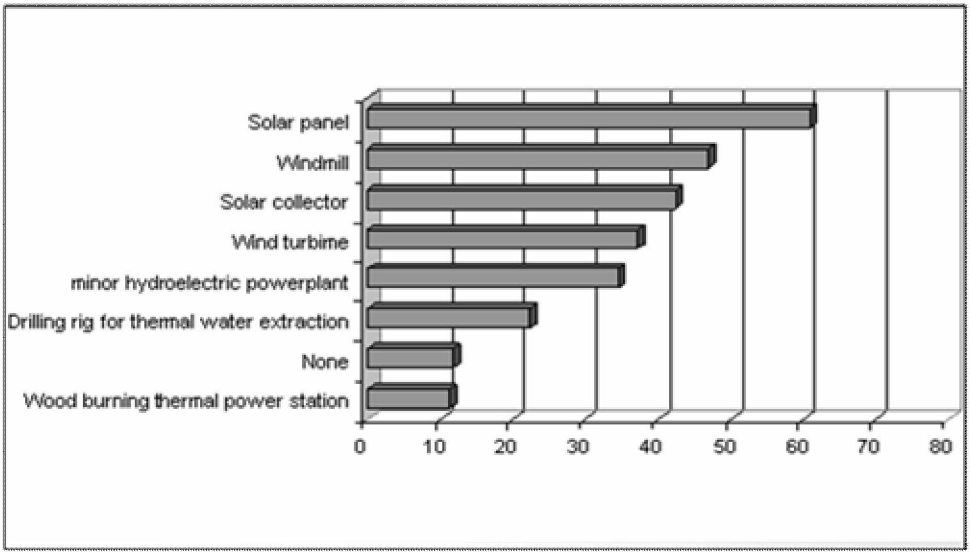


Fig. 1. Social acceptance of instruments (in %) connected to renewable energy sources in the neighborhood of the place residence of the answerers.

The first essential step of wind energetic investments is selection of appropriate location with good natural wind potential. In order to be able to select suitable areas for energetic wind measurements previous meteorological data must be provided. By the virtue of various GIS and statistics calculation methods on the basis of the previously given factors those areas and terrains can be located where construction of a wind farm would be optimal (Rózsavölgyi, 2007) furthermore produced energy could be estimated and predicted. However, methods are needed that are capable of giving a brief about the typical wind potential of sites.

An important structural element of the wind field is the energy content in which respect the quantity is a fundamental question. An overwhelming proportion of the wind energy in Hungary consists of rarely occurring higher wind speeds (Tar, 1991). Thus the monthly number of windy days, when the maximum wind speed exceeds 10 m/s has been included in our discussion. This characteristic of wind field not yet extensively studied. This article analyzes the basic statistics, temporal changes and distribution of such windy days in a longer period (1971-2005), the stochastic connection between the monthly number of windy days and monthly average specific wind power in the decade 1991-2000 and the extrapolation of this connection. Our results permit to estimate the potential wind energy of the given place from the public database of the windy days and contribute to the deeper understanding of the wind climate in Hungary, too.

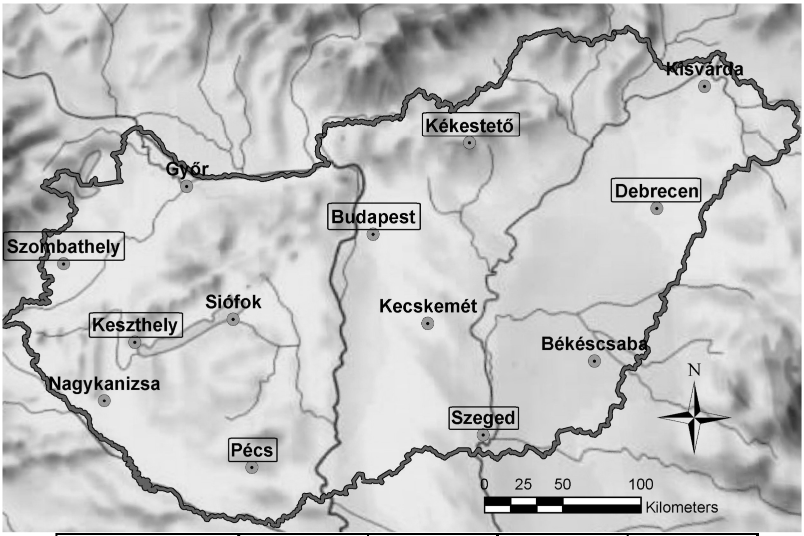
2. Database and methods

The sample taken from the random variable ϑ, describing the number of windy days in a month will be called d10. The source of its elements is the Hungarian Meteorological Service's periodical called Monthly Reports in the period between January, 1971 and December, 2005 (420 months). Data were processed of those originating observation stations where the conditions of wind measurements remained unchanged. The following stations feature monthly data series of windy days that can be considered homogeneous in the above period: Debrecen, Szeged, Budapest-Pestszentlőrinc, Pécs, Keszthely, Szombathely and Kékestető. It should be noted that data for Keszthely is available only from January 1971 to December 1998 (336 months). Fig. 2 shows the geographical locations and exact geographical coordinates (φ: latitude, λ: longitude, h: elevation) of the observatories and anemometer altitudes (h_a). In this paper the basic statistics, distribution and temporal alternation of the monthly windy days (d10) are investigated in the height of anemometer, i. e. of the untransformed elements. Using the hourly wind speeds of period between January, 1991- December, 2000 in these observatories a regression model was applied between the monthly number of windy days and the monthly mean specific wind power calculating with an approximate function.

Specific wind power of a given day of a month can be defined as the area under the curve of the function which approaches the diurnal course of the averages of cubes of wind speeds for each measurement times, multiplied by the half of the density of air.

Characteristics of monthly average specific wind power can be examined via the area under the curve (definite integral) of the trigonometric polynomial fitted to hourly averages of wind speed cubes (Tar, 2004, Tar, 2007a, Tar, 2007b, Tar, 2008). The fitting function is the following:

$$f_2(x) = a_0 + \sum_{m=1}^{2}(a_m \cos\frac{2\pi mx}{N} + b_m \sin\frac{2\pi mx}{N}), \quad (1)$$



observatories	φ	λ	h (m)	h_a (m)
Szombathely	47°16’	16°38’	219	9
Keszthely	46°46’	17°14’	117	15
Pécs	46°00’	18°14’	201	10
Budapest	47°27’	19°13’	130	12
Szeged	46°15’	20°06’	83	9
Debrecen	47°30’	21°38’	111	10
Kékestető	47°52’	20°01’	1011	26

Fig. 2. Geographical locations and exact geographical coordinates (□: latitude, □: longitude, h: elevation) of the observatories and anemometer altitudes (h_a) of the meteorological observatories (framed) comprising the database (Zentai, 1996, Szabó, 2004).

In other words, they are the first two elements of a Fourier series that consists of trigonometric polynomials, where N is the number of diurnal measurements, x=0,1 , 2, …, N-1. The primitive function of approaching function (1) is:

$$F_2(x) = a_0 x + \sum_{m=1}^{2}(\frac{a_m}{\alpha_m}\sin\alpha_m x - \frac{b_m}{\alpha_m}\cos\alpha_m x) \quad (2)$$

where $\alpha_m = \dfrac{2\pi m}{N}$. Therefore if the time series of the averages of wind speed cubes for each measurement times is used to determine a_m and b_m coefficients, then the average specific wind power of one day of the period is:

$$P_{fmd} = \frac{\rho}{2}[F_2(N-1) - F_2(0)]$$

where therefore

$$T_{ac}=F_2(N\text{-}1)\text{-}F_2(0) \qquad (3)$$

is the area under the curve (in m^3/s^3 unit). See an example on Fig. 3.

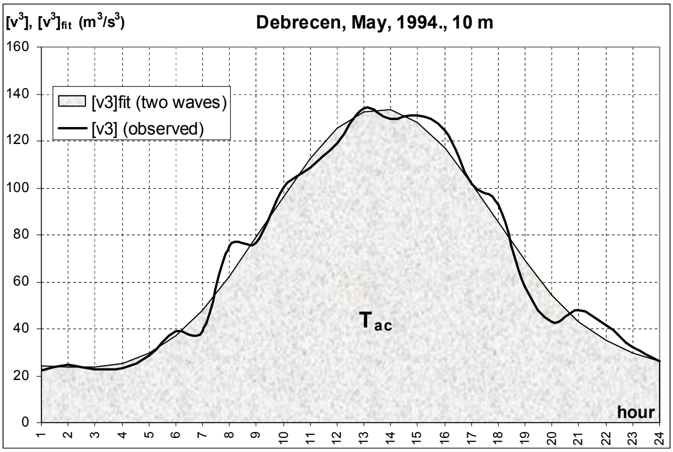


Fig. 3. Values of trigonometric polynomial ($[v^3]_{fit}$) that was fitted to daily run of hourly average of wind speed cubes ($[v^3]$) and area under the curve (T_{ac}) at Debrecen at 10 m height in May, 1991.

3. Time series of the monthly data of windy days

The most important characteristics of the random variable ϑ determined from d10 samples can be found in Table 1 in the two investigated time period (1971-2005 and 1991-2000). It can seen that the p(d10) probability of occurrence of windy days is surprisingly high, with the exception of Keszthely. This is a reassuring fact from the aspect of wind energy utilization. But by the standard deviation, winds are the most even at Keszthely, the reason of this we can make the thermal, i. e. the land and the Lake Balaton breezes wind probable.

Difference between p(d10) values of the two time periods is probably significantly high in Budapest and Pécs. Differences between the average lenghts are higher notably than 1 day only in case of Keszthely. Values of standard deviation show orographic differentiation, since at Szombathely, Keszthely and Pécs (non typical low land stations) are notably higher in the entire time period however, on low land stations (Budapest, Szeged, Debrecen) and at Kékestető (high land station) the situation is reversed or the values are equal. Rest of the parameters cannot be classified in any systems. On the basis of Table 1 the values of average and median are close to each other that might be important in term of distribution examination.

Table 1. Most important statistical characteristics of the time series of monthly windy days (d10) in the two investigated time period (p(d10): probability of the windy day, q_1:lower quartile, q_2: median, q_3: upper quartile).

	Years	p(d10)	mean	st.dev.	var. coeff.	min.	q_1	q_2	q_3	max.
Szombathely	1971-2005	0.4367	13.3	5.1	0.39	2	10	13	17	30
	1991-2000	0.4249	13.2	4.7	0.36	2	10	13	17	26
Keszthely	1971-2005	0.2715	8.3	4.7	0.57	0	5	8	11	24
	1991-2000	0.2105	6.5	4.2	0.64	0	3	6	9	19
Pécs	1971-2005	0.4204	12.8	5.4	0.42	0	9	12	16	28
	1991-2000	0.3676	11.7	4.9	0.42	0	8	12	15	26
Budapest	1971-2005	0.4104	12.5	5.2	0.42	1	9	12	16	27
	1991-2000	0.3893	11.9	5.1	0.43	2	8	11	15	25
Szeged	1971-2005	0.4184	12.7	4.8	0.38	2	10	13	16	27
	1991-2000	0.4112	12.5	4.8	0.39	2	10	12	16	25
Debrecen	1971-2005	0.4006	12.2	5.0	0.41	0	9	12	15	26
	1991-2000	0.4090	12.5	5.4	0.43	3	9	11	16	26
Kékestető	1971-2005	0.6492	19.8	5.0	0.25	5	16	20	24	31
	1991-2000	0.6302	19.2	5.5	0.29	6	15	20	24	29

Table 2 contains further characteristics: modal value defined from empirical distributions, asymmetry (skewness) and kurtosis. The concise analysis of skewness and kurtosis are important for the approximation of the empirical d10 frequency distribution with one of the known discreet frequency functions. Skewness values show that the distribution is closest to symmetrical at Budapest, while it shows rather great asymmetry at other stations. Binomial distribution, whose basic parameter is p, the probability of occurrence of the event in question, is quasi-symmetrical in cases where p is rather close to 0.5 (Yule-Kendall, 1950). As Table 1 shows, this is exactly our case, with the exception of Keszthely. Unfortunately, the binomial distribution does not seem to be an approximation to consider, for the flattenedness of d10 distribution always under that of the binomial one. The skewness value of the Poisson-distribution is $1/\lambda$, where λ is the expected value. From $\lambda=6$ onward this distribution also becomes quasi-symmetric (Yule-Kendall, 1950). By Table 2 we can assume that this occurs in our case, as well.

Table 2: Further statistical characteristics of the time series of monthly windy days (d10)

		Szombathely	Keszthely	Pécs	Buda-pest	Szeged	Debrecen	Kékestető
skewness	1971-2005	0.327	0.608	0.342	0.162	0.240	0.285	-0.435
	1991-2000	0.213	0.714	0.205	0.422	0.352	0.450	-0.344
kurtosis	1971-2005	-0.182	0.182	-0.113	-0.436	-0.273	-0.269	-0.193
	1991-2000	-0.013	0.536	0.224	-0.237	-0.126	-0.542	-0.611
mode	1971-2005	11	6	11	13	10	11	22
	1991-2000	11	2	13	11	10	11	19

We are looking for a distribution whose symmetry and kurtosis properties approximate the respective behavior of d10 values. We assumed the gamma (generalized factorial) distribution as such among continuous distributions. Its density function is

$$f(x) = f(x;\lambda,p) = \frac{\lambda^p}{\Gamma(p)} x^{p-1} e^{-\lambda x}, \qquad \text{if} \qquad x > 0 \tag{4}$$

and

$$f(x)=f(x;\lambda,p)= 0, \qquad \text{if} \qquad x\leq 0 \tag{5}$$

where $\Gamma(p)$ is the generalized factorial (gamma) function. The μ expected value and σ^2 variance of such a probability distribution are

$$\mu = \frac{p}{\lambda}, \qquad \sigma^2 = \frac{p}{\lambda^2} \tag{6}$$

thus parameters p and λ are easy to estimate with the method of moments (Dévényi-Gulyás, 1988, Matyasovszky, 2002). If $p>1$, the distribution has modal value

$$\hat{x} = \frac{p-1}{\lambda} \tag{7}$$

which, according to (6), is always below the average, thus the asymmetry of the gamma-distribution is always left. Another reason that makes this distribution a good practical candidate is that the gamma-distribution with three parameters (x_0, λ, p), is always bounded from below, $x>x_0$ (Csoma and Szigyártó, 1975). $x_0=0$, as a matter of fact, in our case.

Table 3 contains the parameters for the gamma distribution and the calculated modal values using this distribution as well as the empirical modes. The latter two appear to be close enough, with the exception of Budapest and Kékestető. Thus we approximate the empirically observed distribution of the random variable ϑ with the gamma distribution. The goodness (acceptability) of the approximation is determined by the Kolmogorov-Smirnov single sample test (Dévényi and Gulyás, 1988).

Table 3. Parameters (λ, p) of the gamma distribution as well as the value of mode calculated by the gamma distribution and its empirical value.

	Debrecen	Szeged	Budapest	Pécs	Keszthely	Szombathely	Kékestető
λ	0,48	0,55	0,47	0,43	0,37	0,50	0,83
p	5,93	7,13	6,07	5,57	3,05	6,65	16,55
gamma-mode	10,3	11,1	10,8	10,7	5,6	11,4	18,8
empirical mode	11	10	10	11	6	11	22

Fig. 4 shows the frequency distribution of windy days in the period between 1971 and 2005/1998 beside their good approximations according to the Komogorov-Smirnov test. It clearly occurs that the approximation with the gamma-distribution is acceptable for all stations, except Kékestető, at the usual 0.05 significance level. At Kékestető, we found the Poisson distribution to be an acceptable approximation. If the samples are altered to the continuous one by the square-root transformation, they can be fitted with the normal distribution only in Szeged, Pécs, Keszthely and Szombathely.

The observed time series of d10 and the fitting trend lines are shown in Figure 4. The significant difference from 0 of the slope of trend line was checked with a t-test written by Précsényi (1995). By Figure 5 a significant decreasing linear trend has been determined at six observatories. The decrease for 12 months is the strongest in Keszthely (0. 15 day), the sequence further is the next: Kékestető (0.13), Budapest (0.12), Pécs (0.10), Debrecen (0.06) and Szeged (0.04). Consequently, the one day decrease of the monthly number of windy days occurs during 6.7, 7.7, 8.6, 10.3, 15.4 and 25.3 year, in the former order.

4. Time series of T_{ac} that is proportional with monthly average specific wind power

Using the available hourly wind speed database T_{ac} values were determined for every months of period of 1991 – 2000 (at Keszthely 1991-1998) at all of the seven meteorological stations.

In the Table 4 most important factors of T_{ac} are indicated for the period of 1991 – 2000 at the altitude of anemometer. It can be concluded that the biggest specific wind energy place, that was expected, Kékestető and the order after Kékestető is the following: Szombathely, Szeged, Pécs, Debrecen, Budapest, Keszthely. The variation coefficient is the highest at the ulterior station and it is followed by Szombathely, Pécs and Szeged. The possible explanation of the lower values occurrence at the three lowland stations is some sort of orographic dependence.

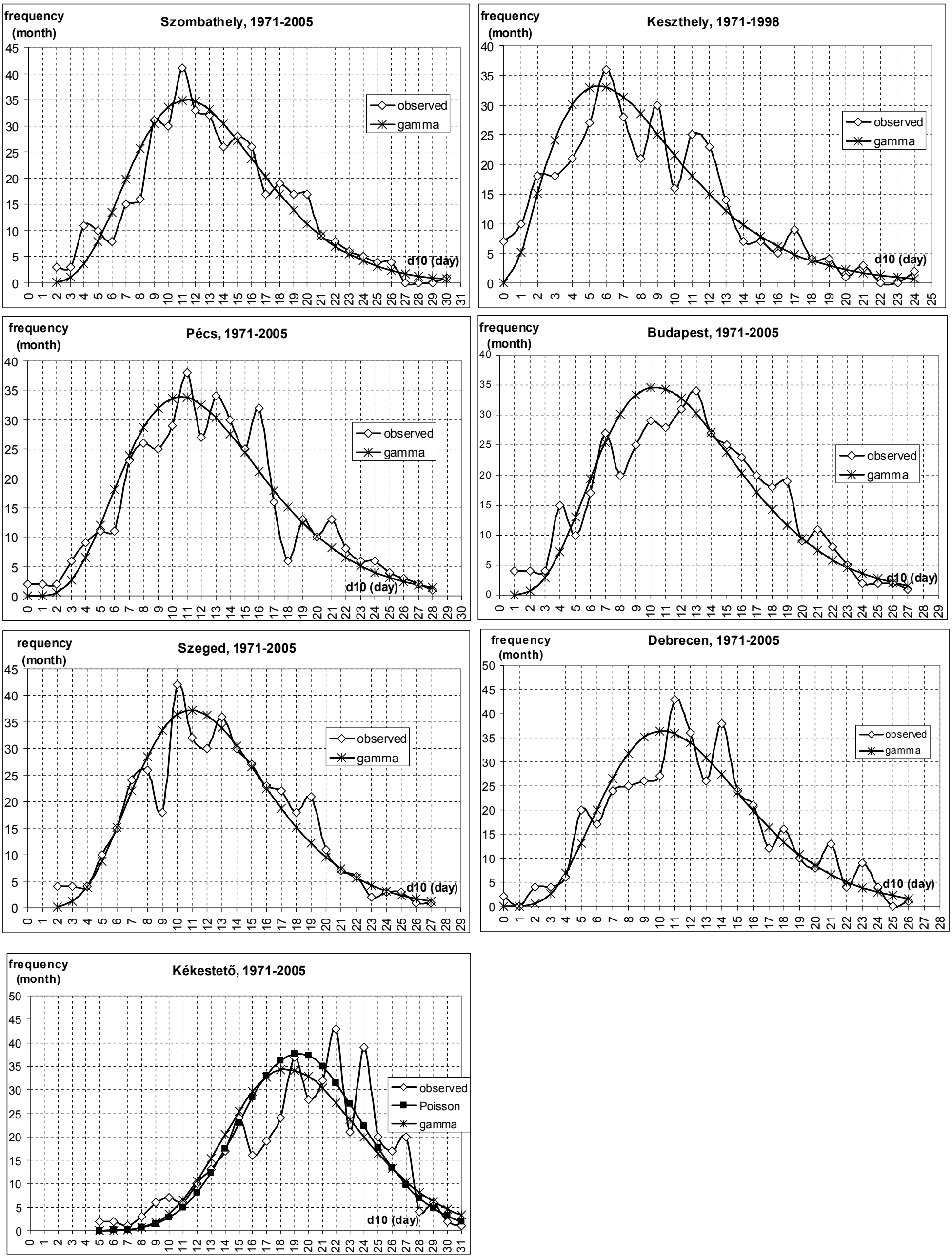


Fig.4. The observed frequency distribution of windy days in the period between 1971 and 2000/1998 beside their good approximations (gamma, Poisson) according to the Komogorov-Smirnov test.

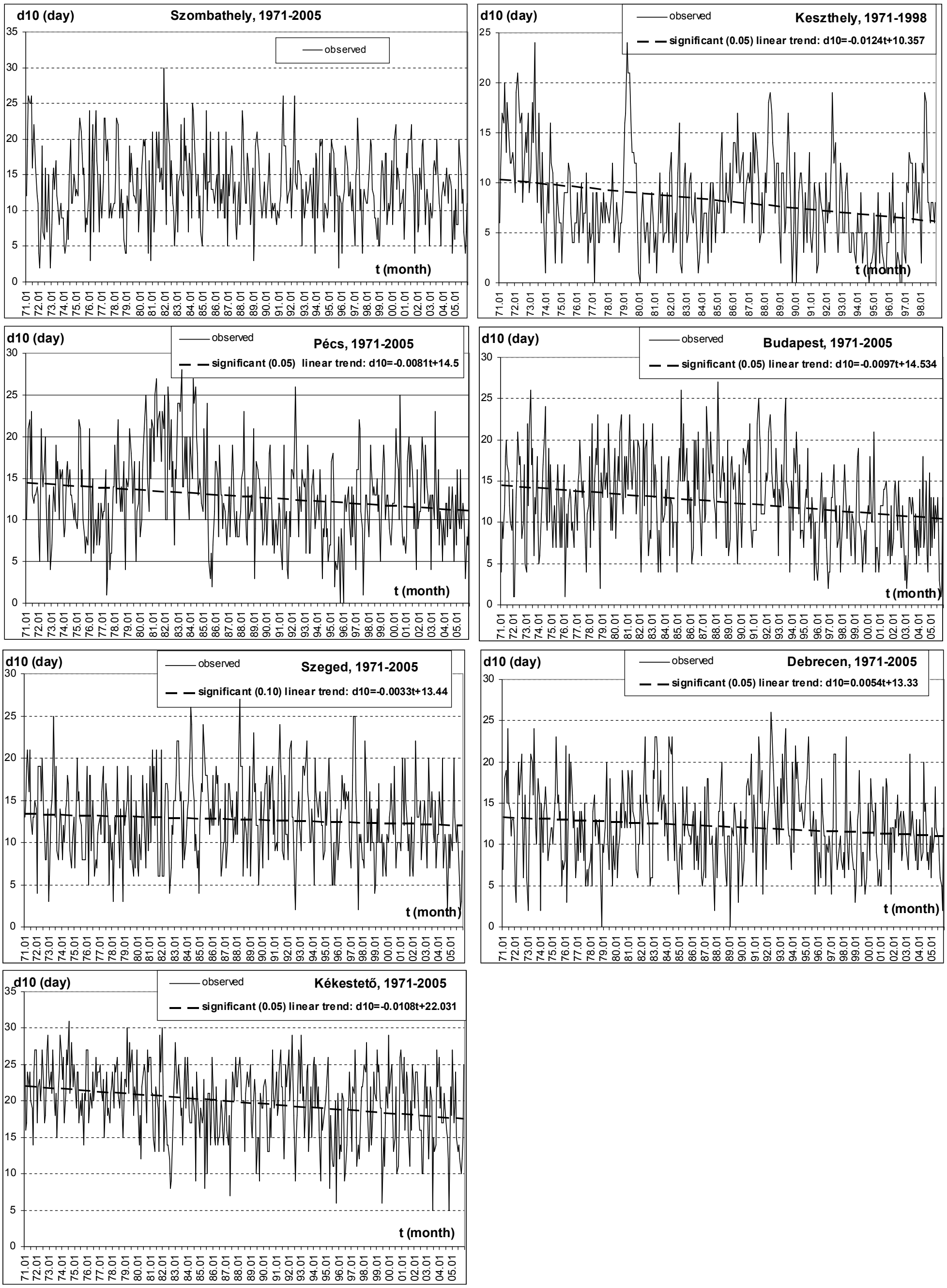


Fig.5. The observed time series of d10 and fitting trend lines.

In general the deviation between the median and average thus approximation with normal distribution is not possible. The oscillation from expanse between the highest and lowest values is big at high wind power places but does not follow the previously defined order above. The absolute maximum can be noticed at Szombathely, which date is May, 1991. The highest values at the other stations are occurred at: Debrecen March,1994; Szeged, Budapest and Keszthely March, 1997; Pécs April, 1999; Kékestető January, 1993. The ulterior does not need to be explained but in case of maximum in January at Pécs we can assume that the reason is Mediterranean cyclones however the minimum in September contradicts to this idea.

Table 4. Most import statistic features (1991-2000) of area under the curve that is proportional with average specific wind performance for day of month (**maximum,** *minimum*).

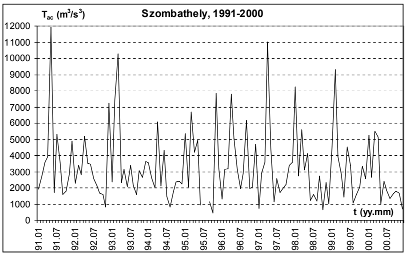
T_{ac}	Szombathely	Keszthely	Pécs	Budapest	Szeged	Debrecen	Kékestető
mean	3254.2	*830.9*	1580.3	907.6	1741	1252.1	**3775.1**
st. deviation	**2161.0**	649.1	895.5	*443.4*	830.3	619.8	2021.5
var. coeff.	0.66	**0.78**	0.57	0.49	*0.48*	0.50	0.54
lower quartile	1796.3	*395.1*	924.0	631.3	1157.7	792.1	**2027.4**
median	2672.1	*621.3*	1456.7	863.6	1680.9	1089.0	**3472.0**
upper quartile	3926.2	*1052.7*	2036.5	1192.9	2208.6	1554.0	**4884.5**
maximum	**11926.3**	3602.7	4702.1	*3051.9*	5839.1	3810.6	10528.3
minimum	443.4	*88.5*	241.5	307.8	474.9	323.5	**922.7**
range	**11482.9**	3514.2	4460.6	*2744.1*	5364.2	3487.1	9605.6
skewness	1.70	**1.83**	1.11	1.53	1.51	1.36	*0.92*
kurtosis	3.39	3.61	*1.01*	4.13	**4.60**	2.40	0.61

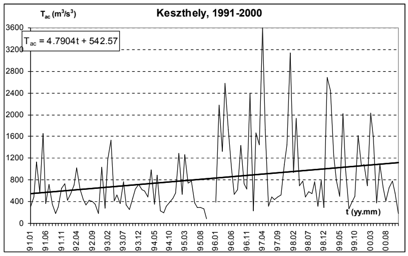
The absolute minimum occurs in October, 1995 at Keszthely. Among the other stations the minima values occur in this month as well at Debrecen, Szeged, and Szombathely. At rest of the stations minimum values occur at Budapest in August 1999; Pécs in September, 1991; Kékestető in April, 1999.

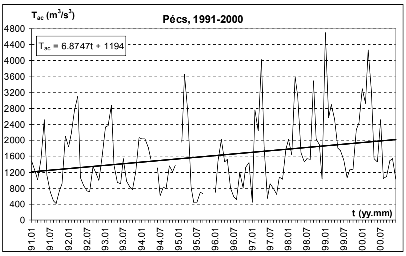
From parameters of skewness and kurtosis consequences can be made that says the distribution has left side asymmetry and is peaked. Hence lower values than average occur with higher possibility everywhere than higher values than average. The frequency distribution of area under the curve (T_{ac}) was approximated by theoretic distributions. Successful approximations by χ^2–test on 0.95 and 0.90 acceptance levels are indicated in Table 5.

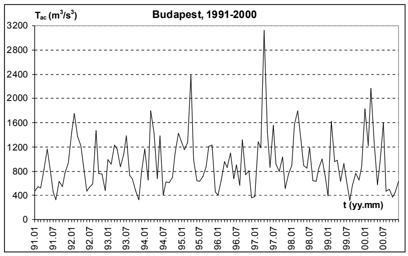
Table 5. Approximate theoretic distributions of T_{ac} at different significance levels (**x** 0.05, + 0.1).

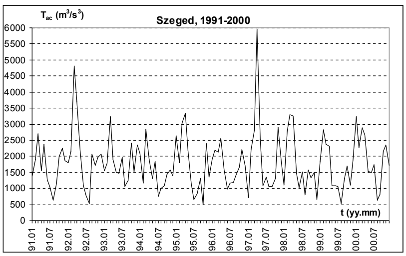
1991-2000.	types of distribution					
	Weibull	Rayleigh	normal	lognormal	square root normal	gamma
Szombathely				+		
Keszthely				+		
Pécs	+	+		**x**	+	+
Budapest	+	+		+	**x**	+
Szeged	+	+	+	+	**x**	+
Debrecen	+	(+)		+	**x**	+
Kékestető	+	+		**x**	+	+

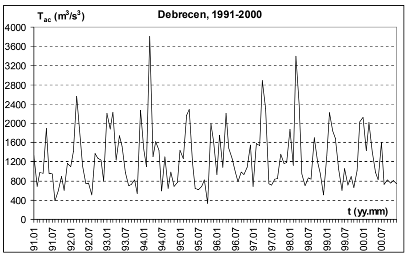












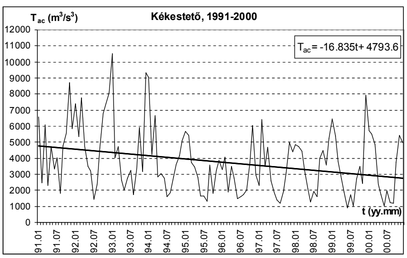


Fig. 6. Time lines (T_{ac}) and its linear trends of areas beneath curve that is proportional with monthly average specific wind performance.

Orographic/geographic differences can be noticed: on lowland territories square root normal approximation and on non lowland territories lognormal approximation proved to be better in addition at Keszthely and Szombathely there are not other distributions within the acceptance level. At the other places Rayleigh distribution appears besides Weibull distribution that makes situation easier because it has just one parameter that can be calculated rather easily from average (Schönwiese, 2000).

According to the Figure 6 linear trend can be found in the monthly time series of areas under the curve by the applied test (Précsényi, 1995) on non lowland stations, except in case of Szombathely. On the basis of equation of trend lines increasing tendency can be noticed in T_{ac} (thus in the monthly average specific wind power) at Pécs and Keszthely with 83(m^3/s^3)/year and 58 (m^3/s^3)/year. At Kékestető this tendency is decreasing that has 202 (m^3/s^3)/year value. On the basis of time periods probability of lower than average values can be determined. These are the followings: Keszthely 0.686, Szombathely 0.627, Pécs 0.626, Budapest 0.600, Debrecen 0.592, Kékestető 0.583, Szeged 0.550. These are in tune with our notice regarding to symmetry of distributions.

5. Regression model for time series of the monthly average specific wind power

In this part of our article the stochastic relation is analyzed by methods of correlation and regression between numbers of monthly windy days and area beneath the curve that is commensurable to monthly specific wind performance that was defined previously. In Table 6 the most important parameters of LCRM(T_{ac},d10) model are indicated namely values of correlation coefficient (r), regression coefficient (b) and regression constant (a, a%).

Table 6. The most important parameters of correlation-regression model: values of correlation coefficient (r), regression coefficient (b) and regression constant (a, a%). (*Italic*: non-significant case, out of the study; ~~xx.x~~: negative T_{ac} is calculated by the regression equations in the case of d10=0).

	Szombathely	Keszthely	Pécs	Budapest	Szeged	Debrecen	Kékestető
r	0.539	*0.115*	0.638	0.487	0.529	0.593	0.728
b	247.98	*17.554*	117.36	43.063	93.768	67.994	269.17
a	-10.784	*668.58*	241.49	423.72	618.82	405.58	-1388.4
a %	~~-0.3~~	*80.3*	15.0	45.4	34.5	32.4	~~-36.8~~

The correlation coefficient is significant at all cases at 0.05 level according to t-test (Yule and Kendall 1950) except at Keszthely. The (T_{ac},d10) significant relation is the weakest at Budapest and the strongest at Kékestető. Average area under the curve belonging to 0 wide windy days is given by the regression constant (a) in our case. On the basis of Table 6 and Figure 7 d10=0 is out of validity interval of regression except in Pécs and Keszthely but the regression equations give negative T_{ac} in case of Szombathely and Kékestető only.

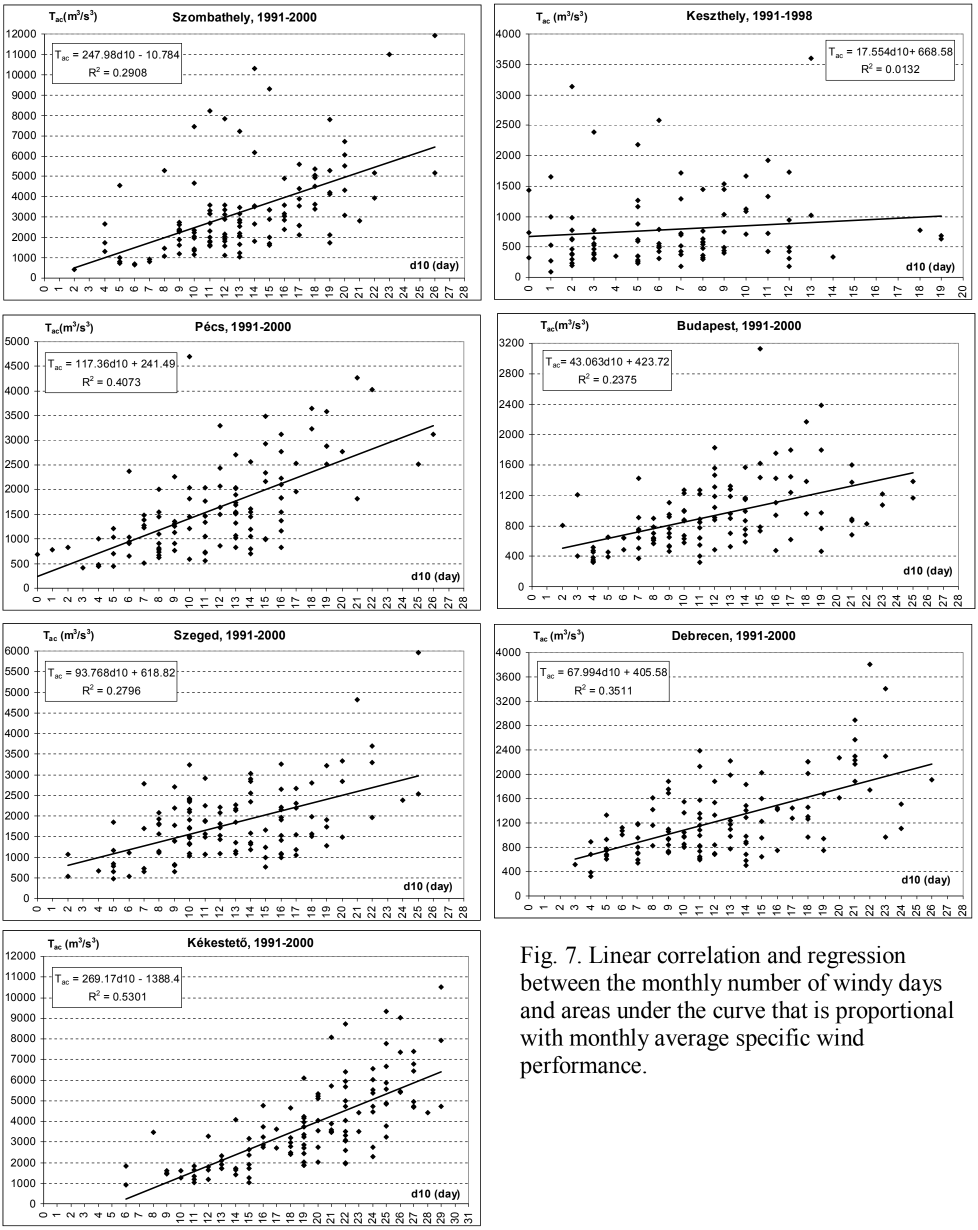


Fig. 7. Linear correlation and regression between the monthly number of windy days and areas under the curve that is proportional with monthly average specific wind performance.

Although the relationship cannot be valueated at Keszthely. According to Table 5 and Figure 7 d10=0 is beyond the pale of validity range of regression except Pécs and Keszthely, but only in the case of Szombathely and Kékestető negative T_{ac} is calculated by equations. At the other stations *a%* parameter was introduced that refers to *a* is how many percent of the average. According to the table, 45 % of monthly average wind power comes from 0 windy day by month in Budapest. These values are over 30 % in Debrecen and Szeged and reach 15 % in Pécs only.

The growth of area under the curve that belongs to change of windy days by one day is shown by *b* regression coefficient. Therefore the sensitivity of predictandus is indicated by change of the predictor. According to the Table 6 the T_{ac}, thus monthly average wind performance as well is the most sensitive at Kékestető and the less sensitive in Budapest for change of d10. Order among them is different from order of correlation coefficients.

In the following part of this paper the error of model will be examined. Time scale (T_{acd10}) of area under curve is restored from d10 values by the help of regression equations and average relative errors of restored time scales are calculated by these regressions. Relative error expressed in % is the following:

$$E_r = \frac{100\,|\,T_{ac} - T_{acd10}\,|}{T_{ac}} \tag{8}$$

In Table 7 the most important statistical features of estimated values (T_{acd10}) and the relative error are indicated at the six stations that have significant regressions.

Table 7. Most important statistical features of the estimated values of area under the curve (T_{acd10}) and the relative error of the model (E_r).

observatory		mean	st. dev.	var. coeff.	max.	min.	range
Szombathely	T_{gad10}	3255.2	1201.5	0.37	6436.7	485.2	5951.5
	E_r (%)	42.2	39.6	0.94	172.2	0.9	171.3
Pécs	T_{gad10}	1612.1	573.2	0.36	3292.9	241.5	3051.4
	E_r (%)	39.6	37.6	0.95	177.4	0.1	177.3
Budapest	T_{gad10}	934.0	221.7	0.24	1500.3	509.8	990.4
	E_r (%)	35.0	32.2	0.92	178.6	0.7	178.0
Szeged	T_{gad10}	1792.5	452.4	0.25	2963.0	806.4	2156.7
	E_r (%)	37.7	31.7	0.84	167.7	0.6	167.1
Debrecen	T_{gad10}	1252.1	367.3	0.29	2173.4	609.6	1563.9
	E_r (%)	34.6	31.9	0.92	170.6	0.0	170.6
Kékestető	T_{gad10}	3773.5	1429.1	0.38	6417.5	226.6	6190.9
	E_r (%)	30.5	28.1	0.92	134.6	0.2	134.4

The modeled time scales concur with the average values of original time scale however, parameters that indicate variability (standard deviation, variation coefficient, range) substantially smaller, by 50 % in general, than in case of the original time scale, hence extreme values are softened by our model. In the decreasing order of previous parameters more notably orographic seclusion can be

seen: in all of the three cases Kékestető, Szombathely and Pécs are on the top three places (non low land and great wind energy places) after them low land stations come next. Since similar order has been detected at out original time scale in case of the variation coefficient consequence can be made that variability average specific wind performance in comparative homogenous orography is lower.
The average of relative error and its deviation is the biggest at Szombathely (42.2%) and smallest at Kékestető and Kékestető is preceded by the three low land stations.

6. Extrapolation in time of the regression model

Summarizing applicability of LCRM(T_{ac},d10) it can be stated that at Keszthely it does not work but at other six stations validity intervals need to be considered to use it. If it is taken strictly these correspond with values between minimum and maximum of d10 base time period (1991-2000) at every station (see Table 1). As a result of our model is used for extrapolation over the base time period then it has to be considered.

At first accordingly the consequences above our model was run on months of 1971-2005. The examined period consists of 420 months and obviously the criteria above are not fulfilled in all cases. In the base time period ratio of d10 values that values occur in the validity interval that is determined by maximal and minima values of d10 in this period these values can be found between 99.8% (Szombathely) and 98.3% (Budapest). T_{acd10} time scales were produced with this method and statistical features of T_{acd10} time scales are indicated in the Table 8 in the record of extrap.1. Due to the big numbers of d10 values that are in the validity interval condition of extrapolation has been changed: all of the positive values that were calculated by the help of regression were accepted. It can be noticed from extrap.2 record of Table 8 that there were only two months that did not meet the requirements. It can be also noticed from this table that among the statistical features only the oscillation was changed notably with the two extrapolations; in the second case it was increased. Thus the other two parameters namely deviation and variation coefficient were not increased significantly. Our previous consequences are confirmed by the latter values of the table: variability of average specific wind performance is less than in homogenous orographic environment.

With all of this concerned henceforth this paper will be continued with examination of tendency of time scales that were calculated by second extrapolation. On the Figure 8 monthly values (T_{acd10}) are illustrated that were calculated by regression. As it can be seen realistic tendency is appeared in original time series T_{ac} only at Pécs, Keszthely and Kékestető. According to Figure 8 it is true except in case of Szeged and Szombathely on the basis of Précsényi's (1995) test. In four cases (Kékestető, Pécs, Budapest, Debrecen) decreasing linear trend were found.

Table 8. Most important statistical features of the extrapolated values of area under the curve in the period 1971-2005 (exrtap.1, extrap.2: see in the above text)

		number of elements	mean	st. dev.	var. coeff.	min.	max.	range
Szombathely	extrap.1	419	3275.7	1255.1	0.38	485.2	6436.7	5951.5
	extrap.2	420	3285.6	1269.8	0.39	485.2	7428.6	6943.4
Pécs	extrap.1	417	1730.9	614.1	0.35	241.5	3292.9	3051.4
	extrap.2	420	1743.1	628.8	0.36	241.5	3527.6	3286.1
Budapest	extrap.1	413	962.2	215.9	0.22	509.8	1500.3	990.4
	extrap.2	420	961.7	225.2	0.23	466.8	1586.4	1119.6
Szeged	extrap.1	418	1806.8	441.5	0.24	806.4	2963.0	2156.7
	extrap.2	420	1813.0	449.5	0.25	806.4	3150.6	2344.2
Debrecen	extrap.1	414	1245.3	327.1	0.26	609.6	2173.4	1563.9
	extrap.2	420	1232.7	338.7	0.27	405.6	2173.4	1767.8
Kékestető	extrap.1	415	3929.5	1308.3	0.33	226.6	6417.5	6190.9
	extrap.2	418	3949.9	1325.6	0.34	226.6	6955.9	6729.3

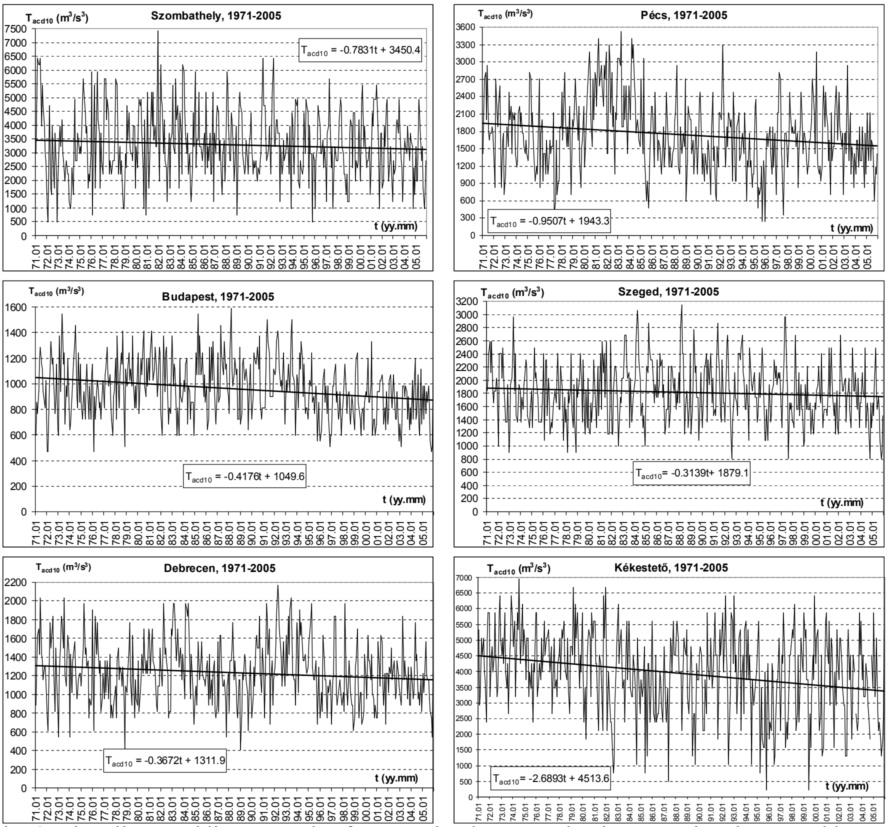


Fig. 8. Time lines and linear trends of area under the curve that is proportional to monthly average specific wind performance, calculated by regression.

7. Conclusion

The approximation of the frequency distribution of windy days with the gamma-distribution is acceptable for all stations, except Kékestető, at the usual 0.05 significance level. At Kékestető, we found the Poisson distribution to be an acceptable approximation.

Significant decreasing linear trend of monthly windy days has been determined at six observatories. The decrease for 12 months is the strongest in Keszthely (0.15 day), the sequence further is the next: Kékestető (0.13), Budapest (0.12), Pécs (0.10), Debrecen (0.06) and Szeged (0.04). Consequently, the one day decrease of the monthly number of windy days occurs during 6.7, 7.7, 8.6, 10.3, 15.4 and 25.3 year, in the former order.

Linear trend can be found in the monthly time series of areas under the approximate curve of the hourly average wind speed cubs (thus in the monthly average specific wind power) on non lowland stations, except in case of Szombathely. On the basis of equation of trend lines increasing tendency can be noticed at Pécs and Keszthely. At Kékestető this tendency is decreasing.

The correlation coefficient between the monthly areas under the approximate curve and the monthly number of windy days is significant everywhere at 0.05 level, except at Keszthely in the time period 1991-2000. The significant relation is the weakest at Budapest and the strongest at Kékestető. The monthly average wind performance is the most sensitive at Kékestető and the less sensitive in Budapest for change of monthly windy days.

By the monthly number of windy days modeled time scales of areas under the approximate curve concur with the average values of original time scale however, parameters that indicate variability (standard deviation, variation coefficient, range) substantially smaller, by 50 % in general, than in case of the original time scale, hence extreme values are softened by our model.

The average and the standard deviation of relative error of the above regression model is the biggest at Szombathely and smallest at Kékestető and Kékestető is preceded by the three low land stations.

The model was extrapolated in time on months of period 1971-2005. The results permit to estimate the potential wind energy of the given place from the public database of the windy days. In four cases (Kékestető, Pécs, Budapest, Debrecen) decreasing linear trend were found in spite of the original time series. We hope, this investigation contributes to the deeper understanding of the wind climate in Hungary, too.

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