Analysis of Data of

AEDB-UNDP (WEP) Wind Masts

Installed in

Gharo-Keti Bandar Wind Corridor

Baburband Mast

Keti-Bandar Mast

Hawksbay-KPT Mast

UNDP-GEF WIND ENERGY PROJECT PAKISTAN

AEDB

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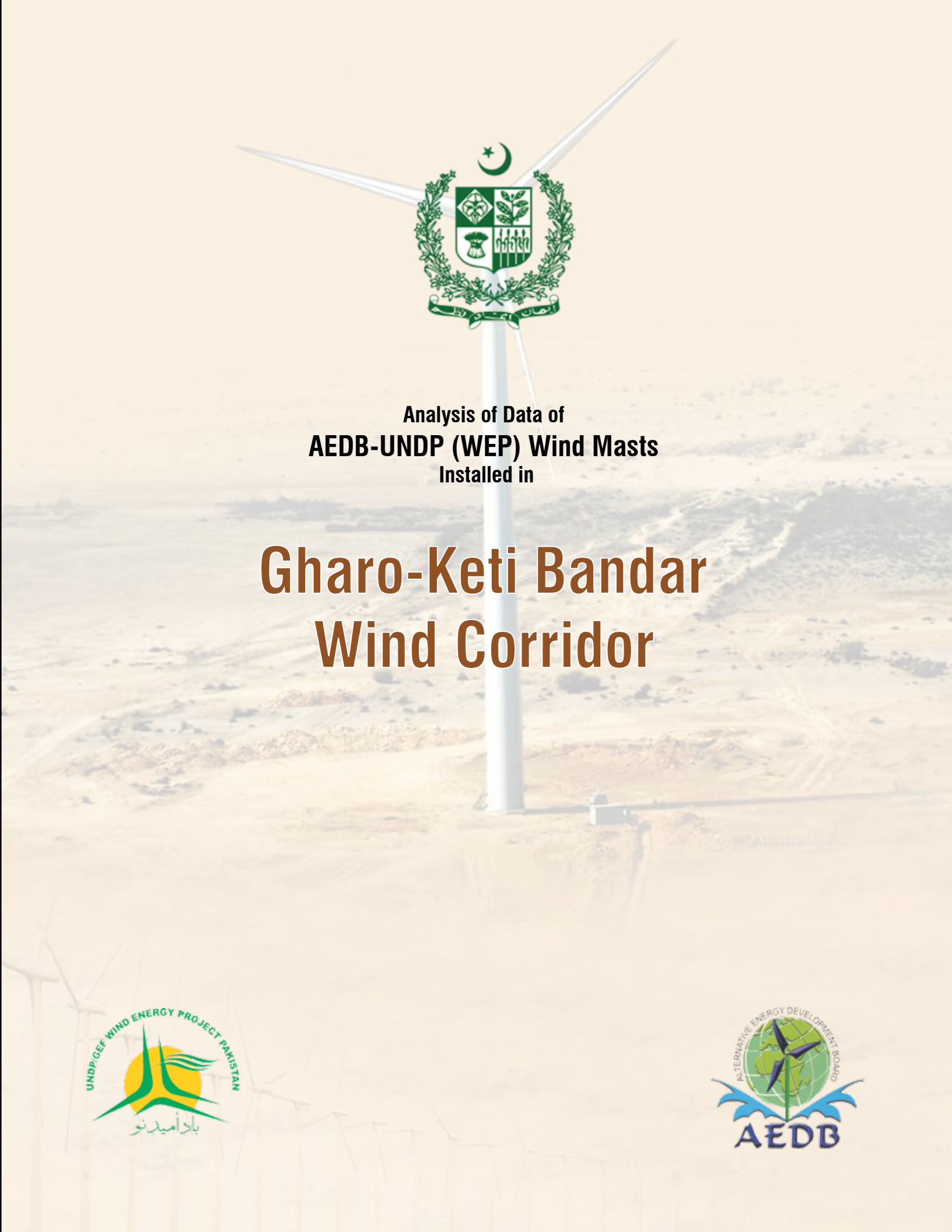

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بادِ اُمید نو

ALTERNATIVE ENERGY DEVELOPMENT BOARD

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Acknowledgements

Apart from the efforts of the AEDB and UNDP (WEP) team, this project owes itself to the contribution of many others. I take this opportunity to express my gratitude to the people who have supported us in the successful installation of wind measuring masts in the Gharo-Keti Bandar Wind Corridor.

I wish to express my deep sense of gratitude to the Chief Executive Officer, AEDB, Mr. Arif Alauddin for his able guidance and invaluable advice at every stage of this study.

Words are inadequate in offering my thanks to the land owners who provided their land for the installation of wind measuring masts. Their cooperation has opened new avenues for the utility scale wind energy development in Pakistan.

I offer my sincere thanks to Mr. Nafees Ahmed Khan, National Project Manager, UNDP Wind Energy Project, for his support in the installation and selection of mast sites in the wind corridor.

Finally, yet importantly, I would like to express my heartfelt thanks to my colleagues, in particular Mr. Aqeel Hussain Jafri, Mr. Irfan Yousuf and Mr. Sheeraz Anwar Khan, who helped me in conducting this study.

Naeem Memon
Deputy Director (Wind)
AEDB.

Message from Chairman

I am pleased to learn that AEDB has achieved the important milestones of identifying potential sites in the Gharo-Keti Bandar Wind Corridor and conducting in-depth resource assessment of these sites. These are crucial steps towards realization of the enormous wind power potential in Pakistan, leading to energy security in the country.

The wind resource assessment of potential sites in the Gharo-Keti Bandar Wind Corridor has resulted in comprehensive databases of the wind regimes in Pakistan. These databases, I believe, will provide of great assistance to wind energy project developers and attract foreign investment to this sector. Thus, AEDB has once again demonstrated its commitment to facilitating the development of private sector wind projects in the country.

The completion of this important project demonstrates our commitment to meeting the energy shortfall in Pakistan in a timely manner. Moreover, the Government is committed to providing electricity to the far reaches of the country. Wind energy will play a vital role not only in powering off-grid areas but also in diversifying our energy portfolio in the coming years. I wish AEDB and wind investors the best of luck in collaborating to take this promising energy sector to new heights.

Preface

The wind data collection and analysis of potential sites is another step forward by Alternative Energy Development Board (AEDB) towards the realization of wind power potential in Pakistan. AEDB is making all out efforts to support the development of renewable energy technologies in the country, in particular wind energy. These technologies are expected to enhance a country's energy security by reducing energy import requirements, reducing supply risks, diversifying its energy portfolio and protecting precious financial and environment resources. Therefore, the Government of Pakistan has tasked AEDB to facilitate renewable energy projects, and AEDB is utilizing all available international assistance to this end.

Until recently, wind energy had been a much neglected energy sector in Pakistan. The non-availability of a legal framework and resource data proved the major bottlenecks. With a legal framework in place in the form of the AEDB Act and Renewable Energy Policy, AEDB is now providing wind project developers with the wind resource data, a major requisite for any wind power project. AEDB, with the collaboration of international donor agencies, has initiated the wind resource assessment of potential wind sites, in accordance with international standards. We believe that this will enable the fast track development of wind energy sector and will assist the project developers in identification and implementation of viable wind power projects.

This report is a part of AEDB's efforts for the facilitation of wind power project developers. AEDB intends to provide similar assistance to project developers in other parts of the country.

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Introduction

Wind energy is one of the fastest growing technologies in the world. Total worldwide wind capacity doubles every three years [1]. In 2009 wind power showed a growth rate of 31.7%, the highest rate since 2001 [1]. Worldwide wind capacity reached 159,213 MW, out of which 38,312 MW were added in 2009 [1]. A total wind capacity of 200,000 Megawatt will be exceeded within the year 2010 [1].

Figure 1: Global Installed Capacity of Wind Energy (source WWEA Report 2009).

The wind sector in 2009 had a turnover of 50 billion € [1]. Asia led the market of new wind installations (40.4%) in 2009, followed by North America (28.4%) and Europe (27.3%) [1]. China continued its role as the locomotive of the international wind industry and added 13,800 MW within a year, more than doubling its installations for the fourth year in a row [1].

Pakistan also made a small contribution to worldwide wind energy capacity in 2009 by establishing a 6 MW wind power project in Jhimpir, Sindh. This was the first phase of a 50MW project which is expected to achieve COD by the end of 2010. Three (03) more projects of 50MW each are expected to achieve COD in the following year, 2011.

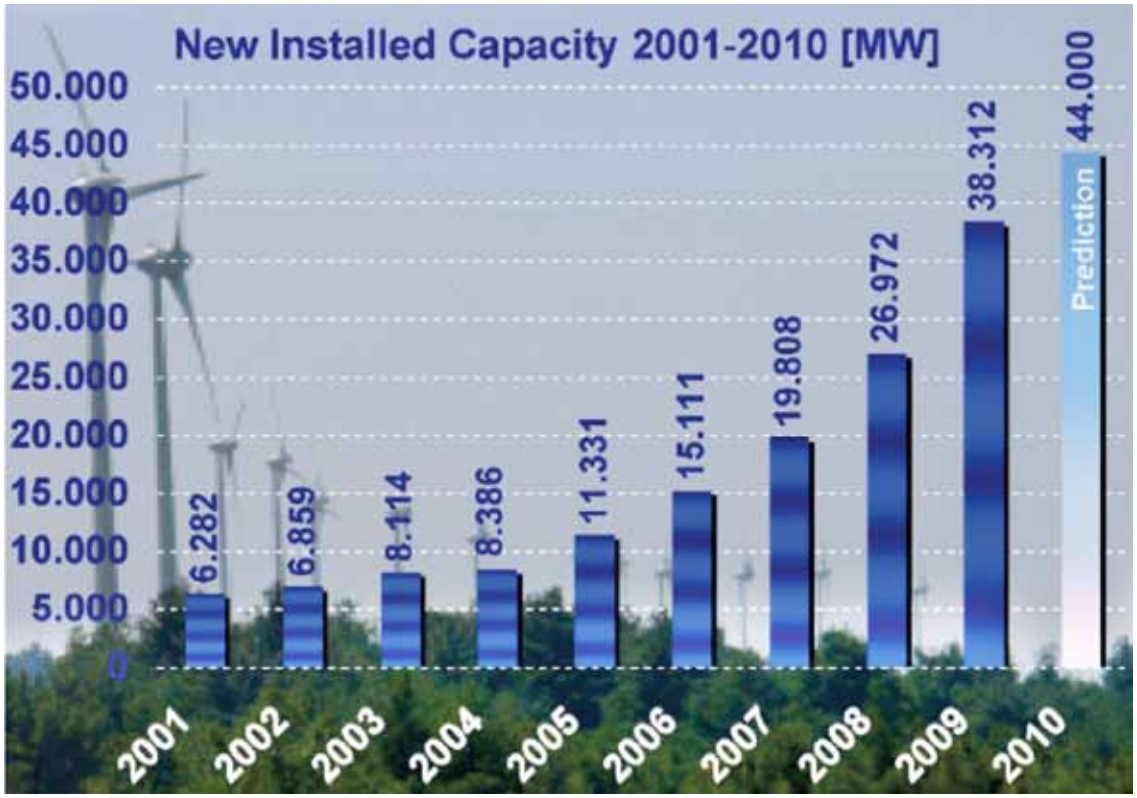

Figure 2: Global New Installed Capacity of Wind Energy (2001-2010). (Source WWEA Report 2009)

Until recently, wind energy did not manage to make significant inroads in Pakistan. This was due to several factors, the most significant of which was the non-availability of reliable long term surface wind speed data. All the international agencies and investors require bankable long term wind data to develop feasibility studies. AEDB shared the wind data collected by Pakistan Meteorological Department (PMD) with private investors/ project developers, but they raised reservations that the data had not been collected according to standard international procedures for collecting wind data.

Therefore, in order to facilitate the growth of wind energy and to minimize the uncertainties related to wind data, AEDB along with UNDP under the GEF funded Wind Energy Program, has started to install wind measuring masts in the potential wind energy areas of Pakistan. In the first phase of this project AEDB and UNDP (WEP) are installing five (05) masts in the Gharo-Keti Bandar Wind Corridor (Figure 3) identified by AEDB and PMD. Out of five (05) masts four (04) wind measuring masts have been installed in the said corridor. This report deals with the wind data analysis of three mast sites and their comparison with each other. The fourth mast has not collected enough data yet to be included in this study. AEDB plans to publish the wind data analysis reports of all these masts on an annual basis.

In the second phase of the AEDB-UNDP (WEP) project, a total of seven (07) masts will be installed in the potential areas of all the four provinces of Pakistan.

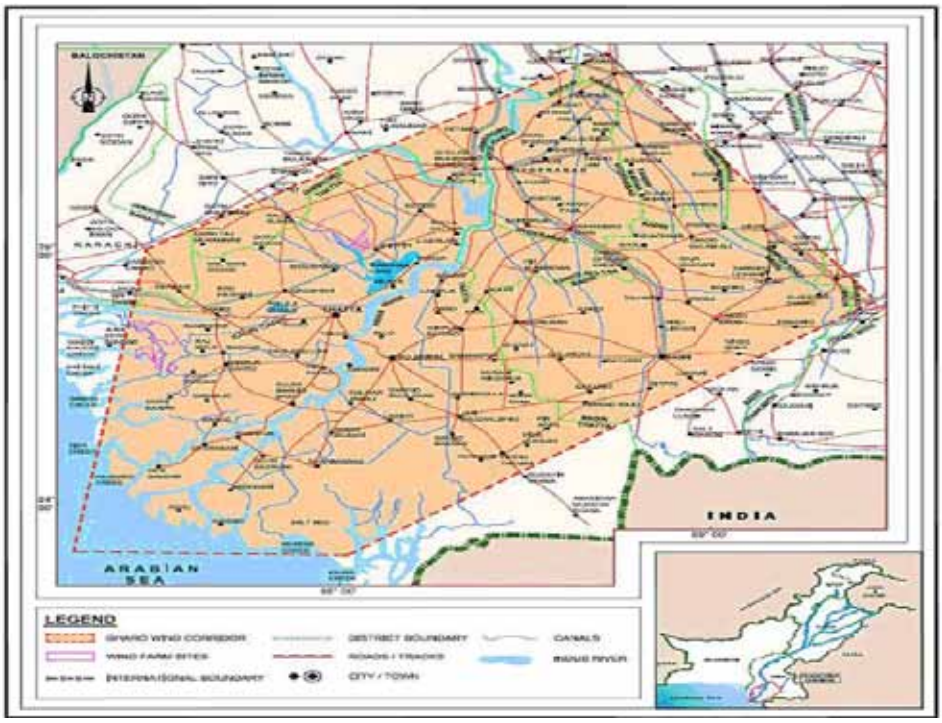

Figure 3: Gharo-Keti Bandar Wind Corridor.

Figure 4 shows the location of the four AEDB UNDP (WEP) masts, indicated in red triangles. A detailed description of each mast site is presented in later sections of this report. Apart from publishing the data analysis reports, AEDB and UNDP will provide wind data of these masts free of charge to interested organizations and individuals for the development of wind energy in the country.

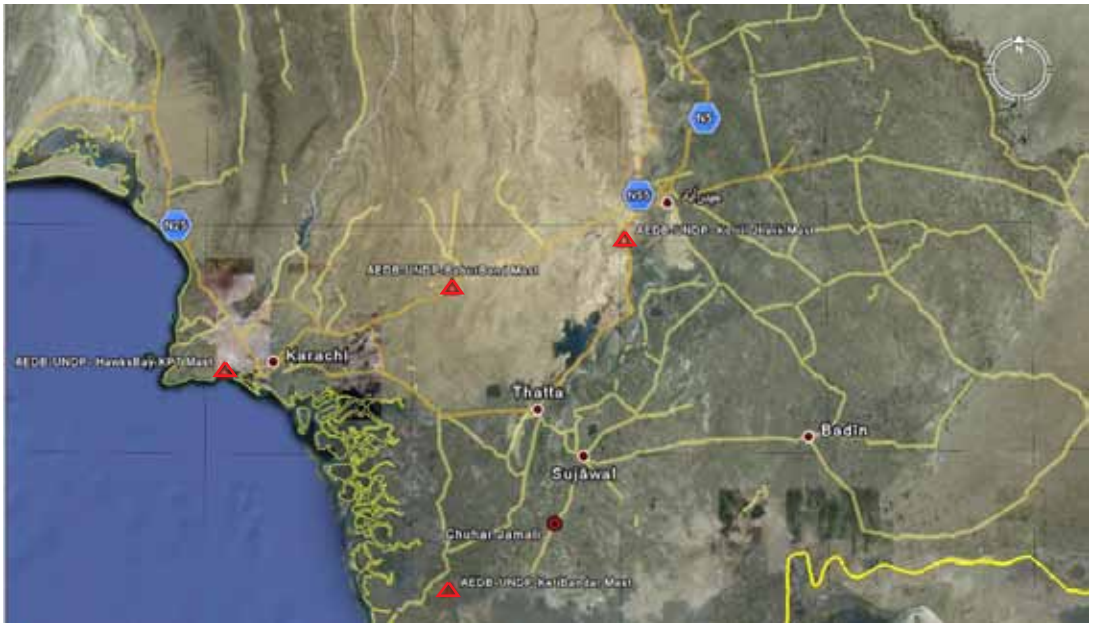

Figure 4: AEDB UNDP (WEP) mast sites in the Gharo-Keti Bandar Wind Corridor.

Baburband

Site Description

The mast site is located in Deh Baburband village, some 67 km in the Northeast of Karachi, along the Super Highway / Motorway (M-9) between Karachi and Hyderabad, bearing coordinates 25° 07′ 36.08″N and 67° 38′ 06.89″E. Baburband mast was installed in June 2008. Since then it has been collecting wind speed data at 10, 30, 60, 80 and 81.5 m heights and wind direction frequencies at 78.5 and 28.5m above ground level.

Baburband mast site is on flat land with low vegetation. The texture of land is hard and rocky. There are no obstacles around the mast. However, the surface roughness of the site has increased since its installation date due to increase in vegetation and construction of single storey buildings (maximum height 3m) in the surroundings. Recently calculated surface roughness of the mast site is 0.0368m and the roughness class is 1.17.

Figure 5: AEDB-UNDP (WEP) Wind Measuring Mast at Baburband.

Figure 6: Surroundings of Baburband Mast.

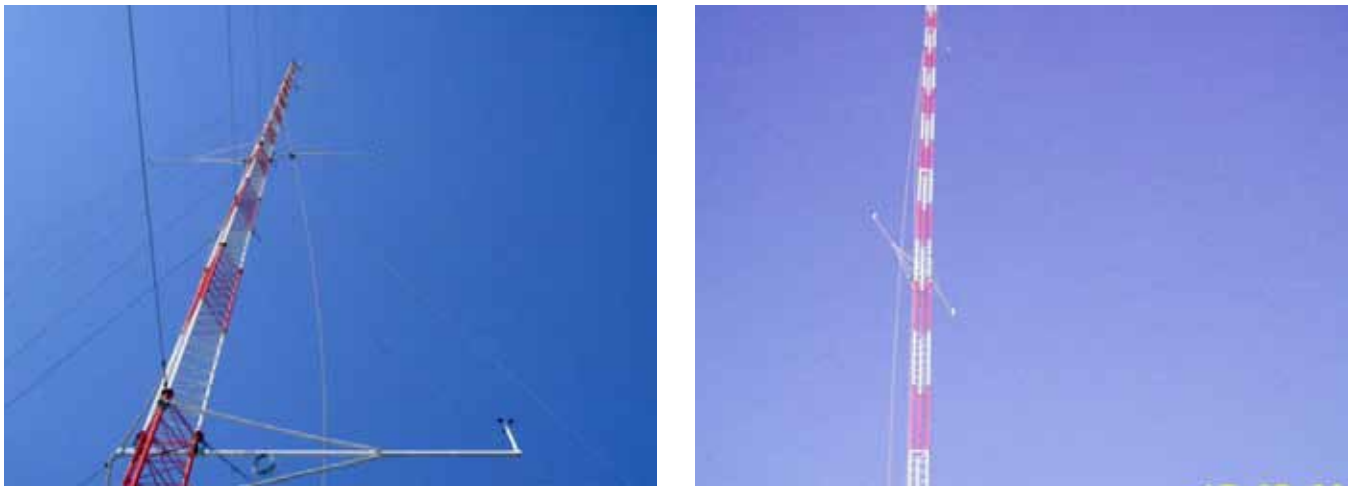

Figure 7: Installation Arrangement of Sensors at Baburband Mast.

Site Data Analysis (June 2008-March 2010)

The 80m mast was installed in June 2008 and since then it has been collecting wind speed data. The time series available for the data analysis of this mast is of 22 months (June 2008-March 2010). Wind shear profile based on the available data is presented in Figure 8 with the measured data in green dots at different levels above ground. The calculated power law exponent is 0.15 which can be used to calculate the wind shear profile at any height.

The wind data recorded at 10, 30, 60, 80 and 81.5 m heights has been analyzed to determine the monthly mean wind speeds. The results are shown in Figure 10 and Table 1-Table 5. The mean annual wind speed is 7.1 m/s, and the average Weibull shape factor (k) is 2.6. Figure 9 shows the wind rose, or wind direction frequency, of Baburband mast for the twenty-two (22) month period. It can be seen from wind rose that the dominant direction of wind at this mast site is southwest.

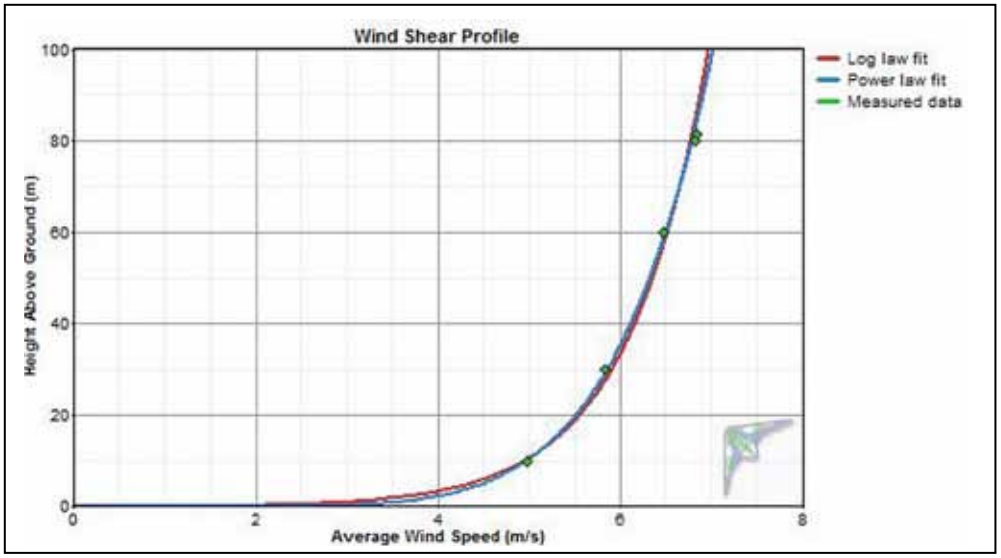

Figure 8: Wind Shear profile for Baburband Mast.

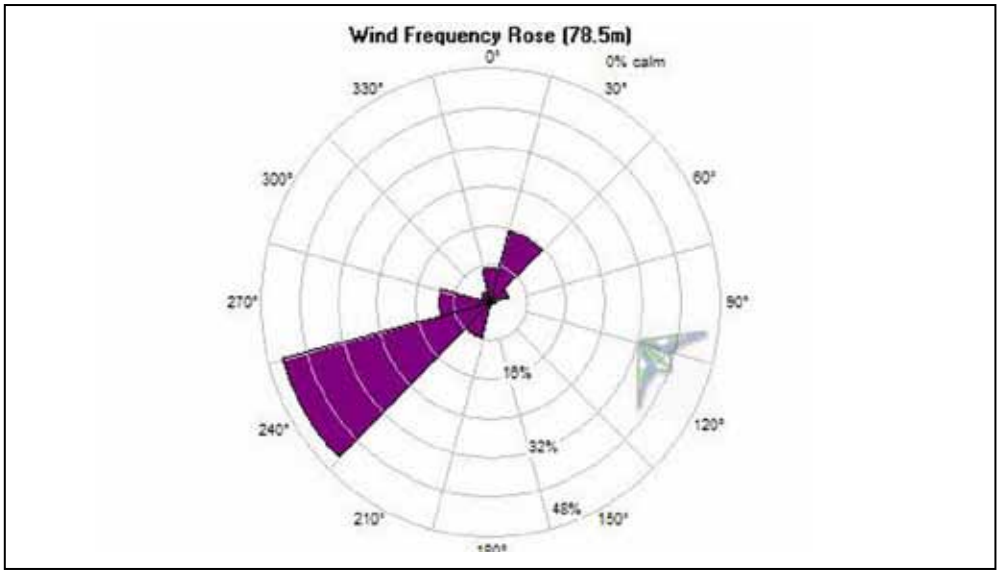

Figure 9: Wind Direction Frequency Distribution for Baburband Mast.

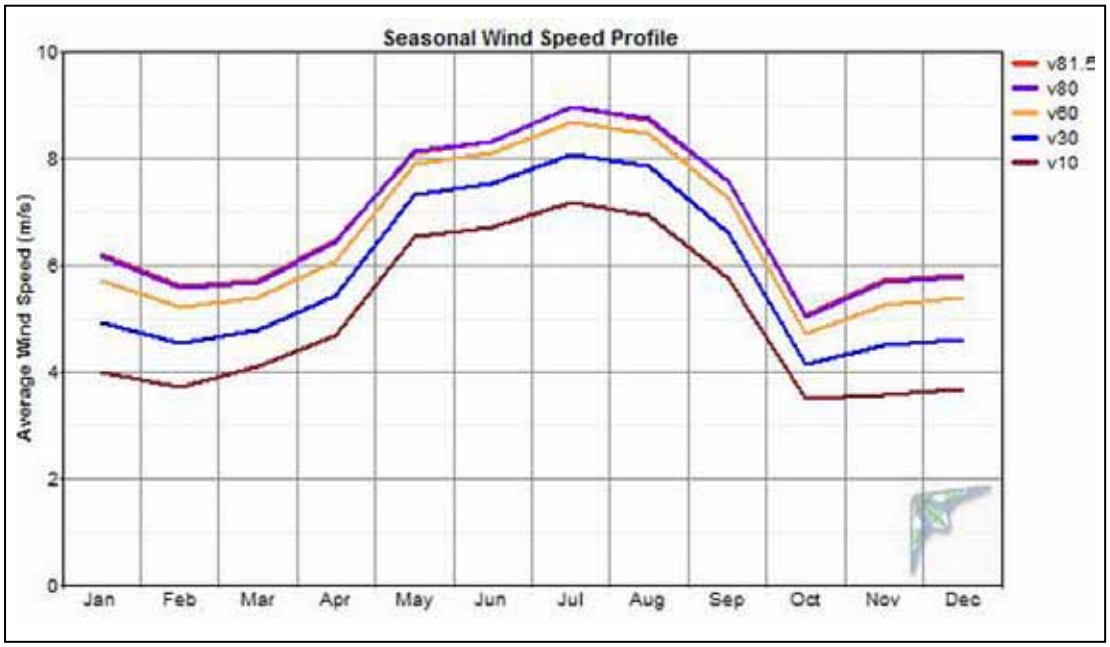

Figure 10: Wind Speed Seasonal profile for Baburband Mast.

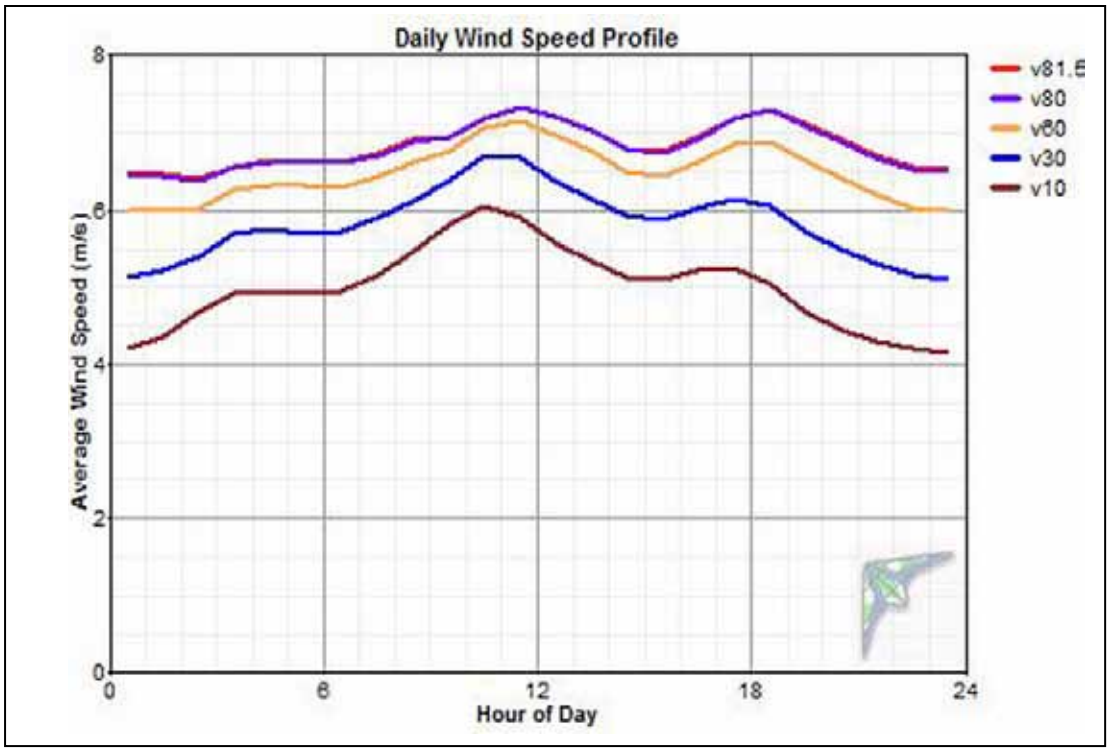

Figure 11: Diurnal Wind Speed profile for Baburband Mast.

The diurnal pattern (Figure 11) of wind speed at the mast site shows that wind speed at this site increases after dawn and remains strong till dusk whereafter it is low in the night time.

Based on the collected data of twenty-two months the mean, minimum and maximum temperatures of this site at 80m height are 25.4, 11.04 and 43.1˚C respectively. At 80m height, the mean power density is 285 W/m^2 and mean turbulence intensity is 0.105. The monthly mean wind speeds recorded as well as data acquisition ratio at different levels (agl) can be seen in Table 1- Table 5.

Level 81.5 m

Year	Month	Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2008	Jun	4,319	100	8.529	1.165	27.69	2.569	3.553	9.42
2008	Jul	4,464	100	9.308	0.308	16.91	2.873	3.704	10.3
2008	Aug	4,464	100	8.984	2.817	15.69	2.191	4.458	9.83
2008	Sep	4,320	100	7.134	0.593	15.28	3.059	2.527	8.04
2008	Oct	4,464	100	5.334	0.126	12.11	2.284	2.537	6.02
2008	Nov	4,320	100	5.840	0.552	13.42	2.536	2.475	6.59
2008	Dec	4,464	100	6.084	0.000	15.01	2.925	2.188	6.86
2009	Jan	4,464	100	6.967	0.573	15.14	2.858	2.669	7.84
2009	Feb	4,032	100	5.705	0.008	12.81	2.583	2.364	6.43
2009	Mar	4,464	100	5.651	0.526	16.70	2.615	2.308	6.39
2009	Apr	4,320	100	6.484	0.202	15.11	2.797	2.485	7.31
2009	May	2,980	66.8	8.137	1.152	16.68	2.404	3.774	9.00
2009	Jun	4,319	100	8.159	0.523	19.38	2.829	3.254	9.10
2009	Jul	4,321	96.8	8.614	0.657	16.55	3.009	3.203	9.61
2009	Aug	4,463	100	8.492	0.250	20.39	2.309	4.280	9.32
2009	Sep	4,320	100	8.012	0.980	13.32	2.066	4.381	8.79
2009	Oct	4,033	90.3	4.840	0.063	14.75	1.938	2.680	5.45
2009	Nov	4,319	100	5.651	0.593	14.62	2.633	2.280	6.39
2009	Dec	4,177	93.6	5.603	0.592	12.55	2.299	2.671	6.30
2010	Jan	4,463	100	5.516	0.001	13.16	2.508	2.351	6.22
2010	Feb	4,032	100	5.525	0.000	14.23	2.669	2.203	6.25
2010	Mar	4,464	100	5.816	0.412	14.16	2.473	2.523	6.56

Table 1: Monthly Wind Speed Records at 81.5m height (agl) for Baburband Mast.

Level 80 m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2008	Jun	4,319	100	8.539	1.115	27.73	2.588	3.541	9.44
2008	Jul	4,464	100	9.328	0.002	16.82	2.898	3.679	10.32
2008	Aug	4,464	100	9.001	2.756	15.79	2.209	4.431	9.85
2008	Sep	4,320	100	7.136	0.445	15.37	3.087	2.502	8.04
2008	Oct	4,464	100	5.300	0.030	12.17	2.316	2.475	5.98
2008	Nov	4,320	100	5.809	0.392	13.40	2.543	2.456	6.55
2008	Dec	4,464	100	6.056	0.000	15.00	2.932	2.164	6.82
2009	Jan	4,464	100	6.936	0.565	15.14	2.864	2.650	7.80
2009	Feb	4,032	100	5.673	0.069	12.86	2.596	2.332	6.40
2009	Mar	4,464	100	5.627	0.414	16.64	2.636	2.277	6.36
2009	Apr	4,320	100	6.462	0.415	15.18	2.827	2.449	7.29
2009	May	2,980	66.8	8.146	1.098	16.76	2.432	3.737	9.02
2009	Jun	4,319	100	8.171	0.355	19.46	2.855	3.220	9.11
2009	Jul	4,321	96.8	8.624	0.677	16.66	3.035	3.179	9.62
2009	Aug	4,463	100	8.505	0.237	20.38	2.329	4.246	9.34
2009	Sep	4,320	100	8.017	0.994	13.39	2.085	4.342	8.80
2009	Oct	4,033	90.3	4.802	0.084	12.13	1.947	2.649	5.41
2009	Nov	4,319	100	5.603	0.550	14.58	2.643	2.254	6.34
2009	Dec	4,177	93.6	5.551	0.550	12.64	2.304	2.634	6.25
2010	Jan	4,463	100	5.464	0.005	13.26	2.512	2.320	6.17
2010	Feb	4,032	100	5.473	0.003	14.27	2.664	2.183	6.19
2010	Mar	4,464	100	5.787	0.316	14.20	2.501	2.484	6.53

Table 2: Monthly wind speed records at 80m height (agl) for Baburband Mast.

Level 60 m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2008	Jun	4,319	100	8.291	0.531	25.51	2.522	3.568	9.17
2008	Jul	4,464	100	9.074	0.128	16.27	2.846	3.642	10.05
2008	Aug	4,464	100	8.729	2.534	15.39	2.184	4.340	9.57
2008	Sep	4,320	100	6.860	0.386	15.04	3.027	2.432	7.73
2008	Oct	4,464	100	4.945	0.000	12.06	2.337	2.257	5.59
2008	Nov	4,320	100	5.383	0.094	13.12	2.327	2.488	6.07
2008	Dec	4,464	100	5.633	0.000	14.56	2.754	2.133	6.34
2009	Jan	4,464	100	6.450	0.538	14.35	2.699	2.607	7.26
2009	Feb	4,032	100	5.307	0.007	12.43	2.455	2.307	5.99
2009	Mar	4,464	100	5.328	0.158	15.90	2.556	2.223	6.03
2009	Apr	4,320	100	6.100	0.059	14.85	2.803	2.324	6.89
2009	May	2,980	66.8	7.903	1.061	16.35	2.406	3.652	8.76
2009	Jun	4,319	100	7.936	0.584	18.89	2.798	3.183	8.86
2009	Jul	4,321	96.8	8.338	0.606	16.41	2.954	3.151	9.31
2009	Aug	4,463	100	8.235	0.526	19.40	2.284	4.176	9.05
2009	Sep	4,320	100	7.680	0.914	13.10	2.077	4.156	8.45
2009	Oct	4,033	90.3	4.481	0.213	12.29	1.885	2.544	5.05
2009	Nov	4,319	100	5.162	0.186	13.88	2.470	2.215	5.84
2009	Dec	4,177	93.6	5.153	0.005	12.34	2.100	2.696	5.79
2010	Jan	4,463	100	5.045	0.000	12.63	2.299	2.337	5.69
2010	Feb	4,032	100	5.153	0.003	13.96	2.518	2.170	5.83
2010	Mar	4,464	100	5.462	0.175	14.04	2.461	2.371	6.17

Table 3: Monthly wind speed records at 60m height (agl) for Baburband Mast.

Level 30 m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2008	Jun	4,319	100	7.730	0.741	22.68	2.363	3.609	8.556
2008	Jul	4,464	100	8.480	0.305	15.51	2.685	3.607	9.394
2008	Aug	4,464	100	8.103	2.190	14.91	2.085	4.226	8.897
2008	Sep	4,320	100	6.276	0.262	14.22	2.865	2.335	7.077
2008	Oct	4,464	100	4.380	0.084	11.52	2.246	2.057	4.950
2008	Nov	4,320	100	4.643	0.116	12.15	2.015	2.459	5.230
2008	Dec	4,464	100	4.864	0.048	13.47	2.436	2.096	5.489
2009	Jan	4,464	100	5.555	0.070	12.83	2.461	2.410	6.255
2009	Feb	4,032	100	4.607	0.000	11.70	2.241	2.170	5.201
2009	Mar	4,464	100	4.752	0.084	14.42	2.403	2.095	5.376
2009	Apr	4,320	100	5.454	0.029	13.96	2.723	2.118	6.167
2009	May	2,980	66.8	7.344	0.916	15.22	2.308	3.53	8.161
2009	Jun	4,319	100	7.386	0.779	16.51	2.630	3.155	8.251
2009	Jul	4,321	96.8	7.688	0.282	15.46	2.739	3.129	8.587
2009	Aug	4,463	100	7.620	0.670	18.25	2.174	4.048	8.395
2009	Sep	4,320	100	6.978	0.733	12.68	2.049	3.820	7.718
2009	Oct	4,033	90.3	3.896	0.064	11.05	1.755	2.359	4.397
2009	Nov	4,319	100	4.374	0.221	12.82	2.165	2.129	4.945
2009	Dec	4,177	93.6	4.392	0.155	11.38	1.789	2.666	4.938
2010	Jan	4,463	100	4.302	0.000	10.47	1.934	2.369	4.847
2010	Feb	4,032	100	4.466	0.089	12.94	2.261	2.087	5.050
2010	Mar	4,464	100	4.877	0.173	13.04	2.332	2.222	5.514

Table 4: Monthly wind speed records at 30m height (agl) for Baburband Mast.

Level 10 m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2008	Jun	4,319	100	6.895	0.526	18.69	2.124	3.622	7.636
2008	Jul	4,464	100	7.561	0.429	13.87	2.409	3.586	8.380
2008	Aug	4,464	100	7.157	1.642	13.31	1.876	4.160	7.867
2008	Sep	4,320	100	5.467	0.269	12.62	2.586	2.258	6.177
2008	Oct	4,464	100	3.794	0.000	10.35	2.004	2.021	4.300
2008	Nov	4,320	100	3.711	0.231	11.19	1.736	2.270	4.197
2008	Dec	4,464	100	3.971	0.061	11.80	2.175	1.915	4.483
2009	Jan	4,464	100	4.577	0.186	11.12	2.216	2.184	5.168
2009	Feb	4,032	100	3.840	0.172	10.60	1.995	2.037	4.344
2009	Mar	4,464	100	4.081	0.196	12.60	2.175	1.995	4.621
2009	Apr	4,320	100	4.709	0.169	12.40	2.526	1.978	5.330
2009	May	2,980	66.8	6.545	1.051	13.47	2.124	3.419	7.287
2009	Jun	4,319	100	6.593	0.658	14.02	2.371	3.123	7.370
2009	Jul	4,321	96.8	6.806	0.299	13.76	2.424	3.129	7.602
2009	Aug	4,463	100	6.759	0.691	15.37	1.980	3.943	7.456
2009	Sep	4,320	100	6.053	0.307	11.19	1.914	3.556	6.723
2009	Oct	4,033	90.3	3.230	0.319	9.28	1.516	2.266	3.655
2009	Nov	4,319	100	3.459	0.000	11.22	1.867	1.969	3.915
2009	Dec	4,177	93.6	3.416	0.193	9.37	1.541	2.356	3.858
2010	Jan	4,463	100	3.433	0.000	8.91	1.608	2.279	3.884
2010	Feb	4,032	100	3.656	0.000	11.00	1.978	1.961	4.138
2010	Mar	4,464	100	4.202	0.268	11.66	2.134	2.095	4.759

Table 5: Monthly wind speed records at 10m height (agl) for Baburband Mast.

Hawksbay-Karachi Port Trust

Site Description

The 80 m tall mast is located on the premises of Karachi Port Trust (KPT) on the Hawksbay coast in Karachi. Geodetic position of the mast is 24° 52′ 02.025″N and 66° 51′ 41.983″ E. Wind speed at Hawksbay-KPT mast is recorded through a data logger manufactured by Wilmers. This logger is connected with the anemometers placed at 10, 30, 60 and 2x80 m heights and wind vanes at 78.5 and 28.5m (Figure 14).

The mast site is on flat land with very low vegetation (Figure 12). There are no major wind breakers in the dominant direction of the wind, apart from a few multi storey buildings in the north of mast site. Surface roughness of the mast site is 0.00232m and the roughness class is 0.49. The mast site has low soil bearing capacity due to marshy conditions; Figure 13 presents the features of site.

Figure 12: AEDB-UNDP (WEP) Hawksbay-KPT Mast.

Figure 13: Panoramic View of Hawksbay-KPT Mast.

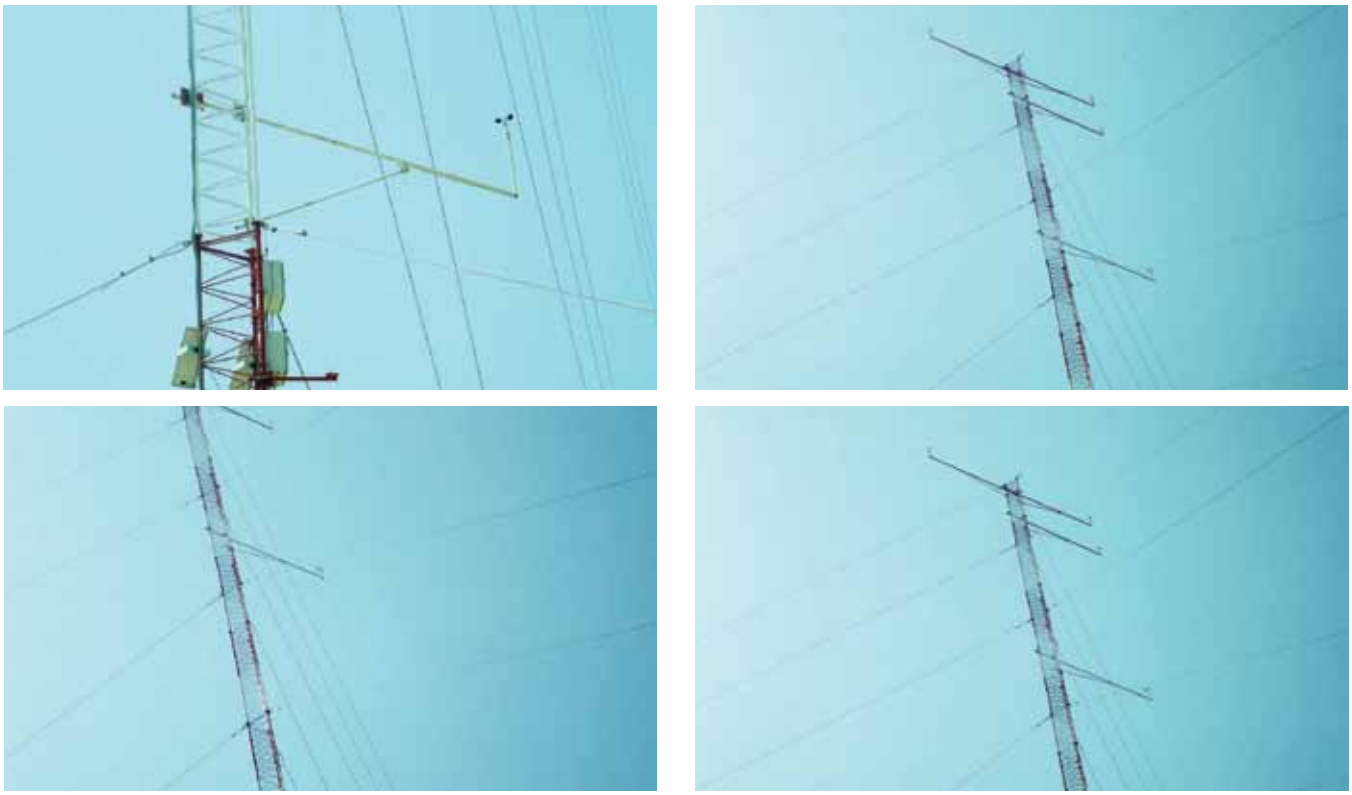

Figure 14: Installation Arrangement of Sensors at Hawksbay-KPT Mast.

Site Data Analysis

The 80 m mast started collecting wind data in March 2009. Therefore the time series available for data analysis of this mast is of 13.2 months (March 19, 2009- April 24, 2010). Wind shear profile based on the available data is presented in Figure 15 with the measured data in green dots at different levels above ground level. The calculated power law exponent is 0.106 which can be used to calculate the wind shear profile at any height.

Table 6-Table 9 and Figure 15 show the mean monthly wind speeds calculated from wind data recoded at 10, 30, 60 and 80 m heights at Hawksbay-KPT mast. The mean annual wind speed is 5.9 m/s, and the average Weibull shape factor (k) is 3.23. Figure 16 shows the wind rose, or wind direction frequency, of Hawksbay-KPT mast for the thirteen month period. It can be seen that the dominant direction of wind at this mast site is southwest.

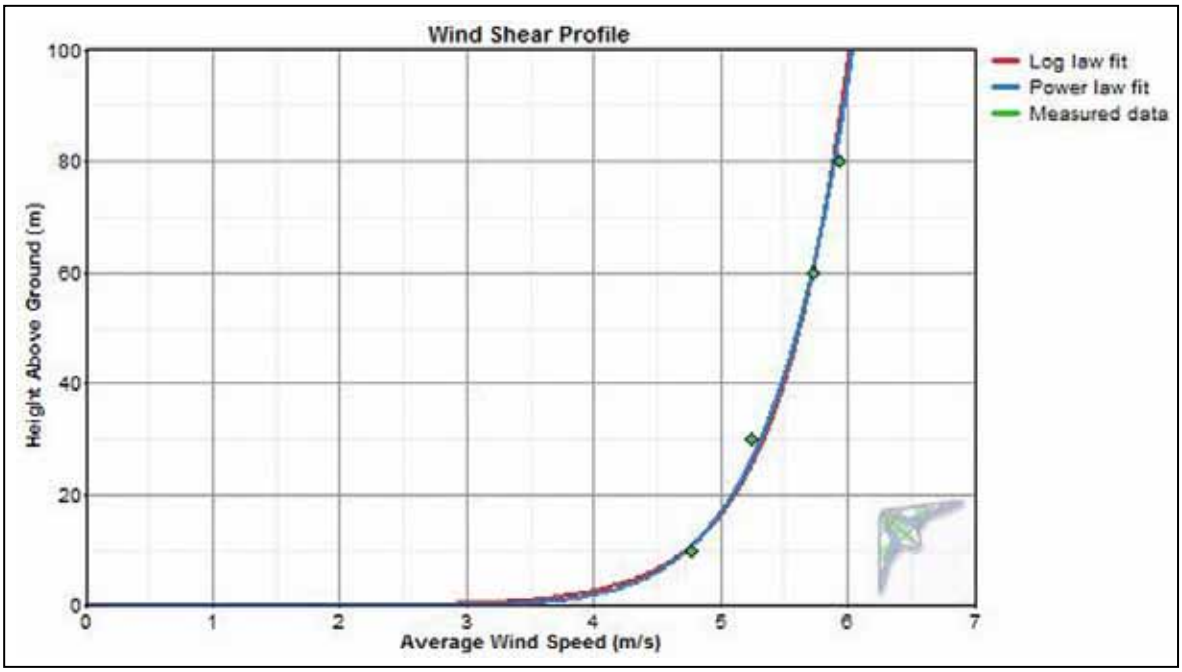

Figure 15: Wind Shear profile for Hawksbay-KPT Mast.

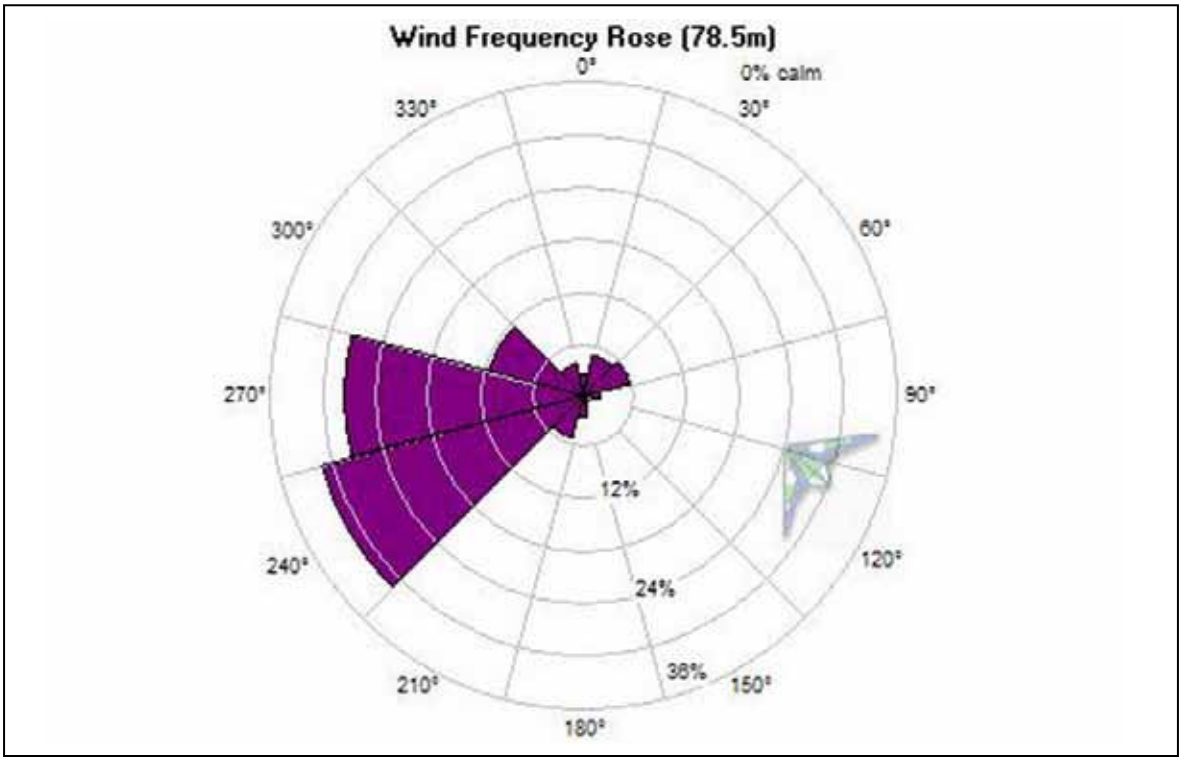

Figure 16: Wind Direction Frequency Distribution for Hawksbay-KPT Mast

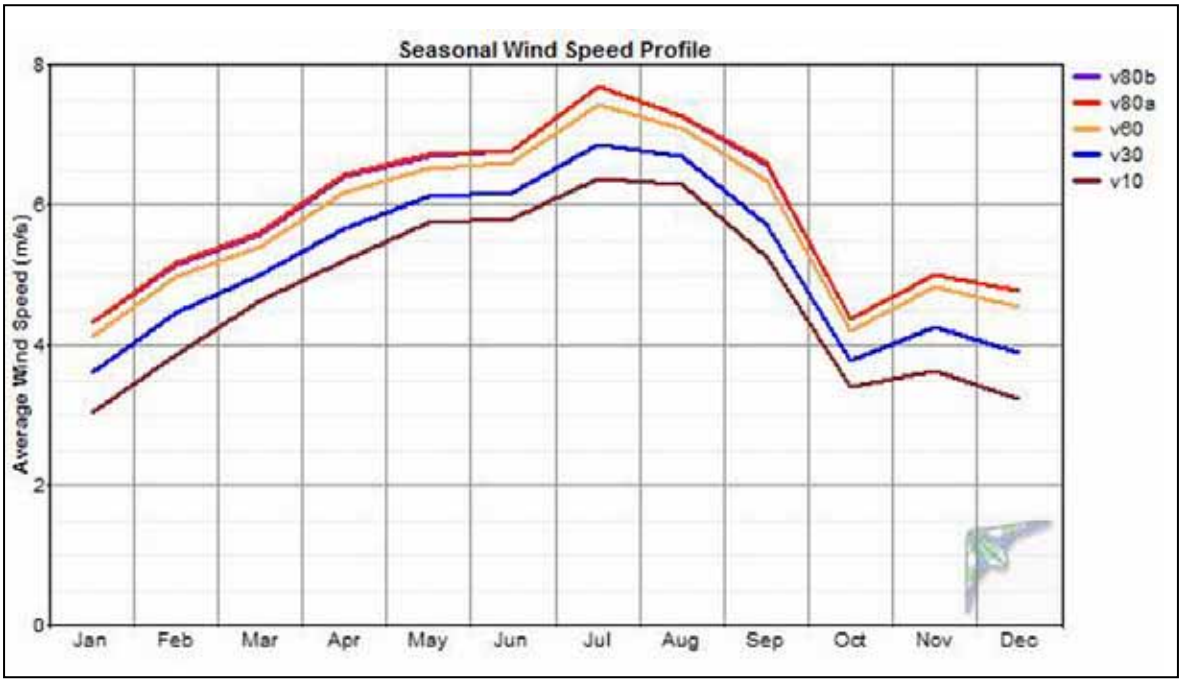

Figure 17: Wind Speed Seasonal profile for Hawksbay-KPT Mast.

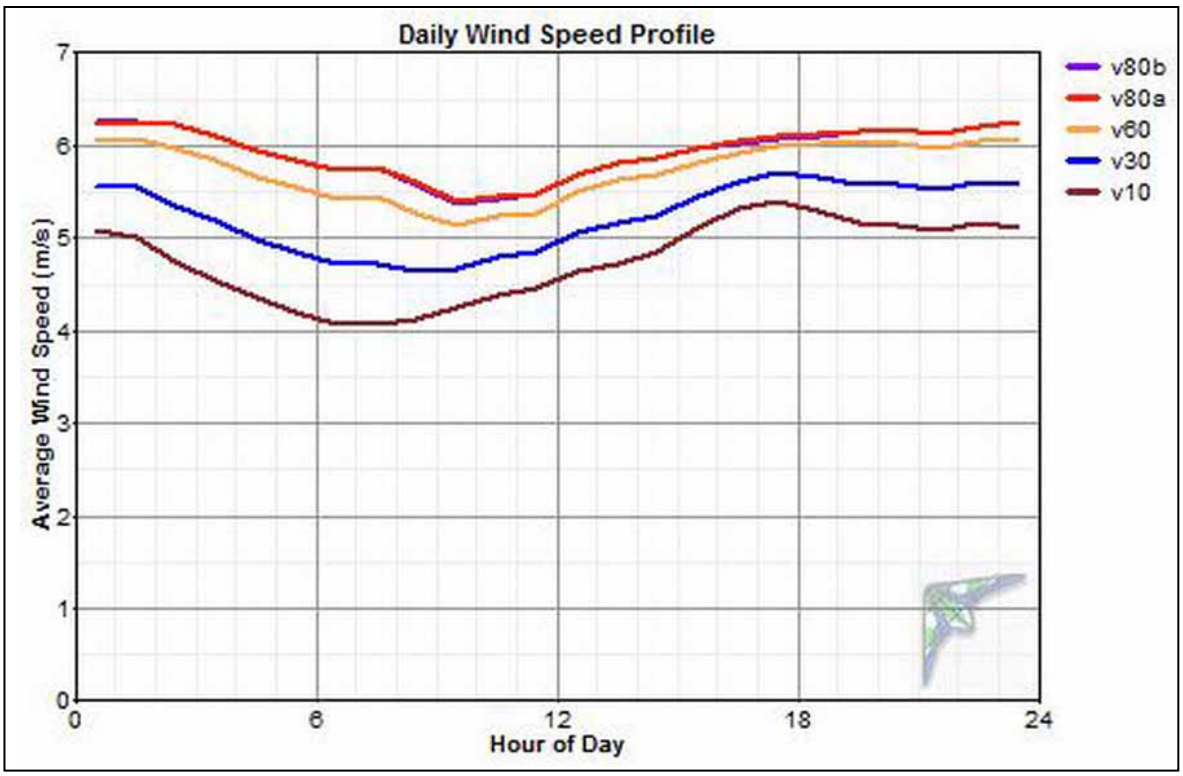

Figure 18: Diurnal Wind Speed profile for Hawksbay-KPT Mast.

The diurnal pattern (Figure 18) of wind speed at the mast site shows that wind speed at this site increases after dusk, remains strong till dawn and is lowest at noon.

The wind data gathered from the Hawksbay-KPT mast for the period of 13.2 months (from March 2009 to April 2010) indicates that the mean, minimum and maximum temperatures of this site at 80 m height are 26.16, 13.9 and 38.8°C, respectively. At 80m height, the mean power density is 194 W/m^2 and mean turbulence intensity is 0.0921. The monthly mean wind speeds recorded with data acquisition ratio at different levels (agl) are given in Tables 6-12. It is to be noted that this mast has started collecting wind data from 19th of March 2009 which is evident from the data recovery ratio mentioned in the table below for March 2009. The data up to 24th April 2010 is used for this analysis and hence the same is reflected from the data recovery rate of April 2010.

Level 80m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2009	Mar	1,778	100	5.502	0.219	12.33	2.325	2.556	6.195
2009	Apr	4,320	100	6.235	0.197	14.93	2.482	2.746	7.009
2009	May	4,464	100	6.716	0.547	14.01	2.287	3.284	7.489
2009	Jun	4,320	100	6.791	0.508	15.77	2.471	3.018	7.605
2009	Jul	4,464	100	7.707	1.150	19.47	2.105	3.932	8.480
2009	Aug	4,464	100	7.258	0.270	12.48	2.157	3.957	8.016
2009	Sep	4,320	100	6.606	0.896	12.80	1.768	4.091	7.269
2009	Oct	4,464	100	4.388	0.2.00	12.48	2.063	2.258	4.958
2009	Nov	4,320	100	5.017	0.049	16.37	2.867	1.868	5.675
2009	Dec	4,032	90.3	4.779	0.212	11.64	2.214	2.291	5.400
2010	Jan	4,176	93.5	4.318	0.000	11.06	1.811	2.539	4.852
2010	Feb	4,032	100	5.175	0.159	12.70	2.284	2.414	5.840
2010	Mar	4,464	100	5.672	0.484	13.20	2.438	2.497	6.392
2010	Apr	3,312	100	6.704	0.355	15.50	2.798	2.558	7.556

Table 6: Monthly Wind Speed Records at 80m height (agl) for Hawksbay-KPT Mast.

Level 60m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2009	Mar	1,778	100	5.332	0.376	12.26	2.331	2.460	6.012
2009	Apr	4,320	100	5.996	0.299	14.45	2.471	2.645	6.751
2009	May	4,464	100	6.541	0.548	13.44	2.282	3.196	7.300
2009	Jun	4,320	100	6.612	0.383	15.28	2.434	2.980	7.411
2009	Jul	4,464	100	7.452	0.919	18.85	2.068	3.891	8.207
2009	Aug	4,464	100	7.104	0.278	12.20	2.145	3.884	7.854
2009	Sep	4,320	100	6.354	0.723	12.74	1.810	3.840	7.018
2009	Oct	4,464	100	4.211	0.023	10.78	2.049	2.177	4.760
2009	Nov	4,320	100	4.835	0.190	16.15	2.668	1.926	5.469
2009	Dec	4,032	90.3	4.544	0.133	10.90	1.965	2.461	5.121
2010	Jan	4,176	93.5	4.135	0.129	10.86	1.687	2.639	4.647
2010	Feb	4,032	100	4.974	0.223	12.37	2.214	2.392	5.612
2010	Mar	4,464	100	5.464	0.251	12.56	2.406	2.432	6.160
2010	Apr	3,312	100	6.454	0.437	14.52	2.729	2.537	7.278

Table 7: Monthly wind speed at 60m height (agl) for Hawksbay Mast.

Level 30m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2009	Mar	1,778	100	4.918	0.29	11.76	2.349	2.217	5.55
2009	Apr	4,320	100	5.485	0.281	13.9	2.448	2.406	6.186
2009	May	4,464	100	6.114	0.216	12.33	2.242	3.026	6.839
2009	Jun	4,320	100	6.184	0.238	14.23	2.33	2.902	6.937
2009	Jul	4,464	100	6.883	0.898	17.13	1.993	3.761	7.602
2009	Aug	4,464	100	6.703	0.133	11.44	2.084	3.743	7.42
2009	Sep	4,320	100	5.736	0.545	12.13	1.904	3.291	6.396
2009	Oct	4,464	100	3.794	0.108	9.93	2.018	1.979	4.288
2009	Nov	4,320	100	4.274	0.155	15.67	2.465	1.846	4.826
2009	Dec	4,032	90.3	3.9	0.134	10.62	1.57	2.643	4.383
2010	Jan	4,176	93.5	3.625	0.118	10.6	1.506	2.588	4.082
2010	Feb	4,032	100	4.471	0.145	11.94	2.11	2.246	5.051
2010	Mar	4,464	100	5.037	0.159	12.1	2.369	2.254	5.682
2010	Apr	3,312	100	5.9	0.318	13.34	2.646	2.394	6.662

Table 8: Monthly wind speed at 30m height (agl) for Hawksbay Mast.

Level 10m									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2009	Mar	1,778	100	4.593	0.062	11.19	2.366	2.014	5.173
2009	Apr	4,320	100	5.050	0.188	13.07	2.443	2.189	5.70
2009	May	4,464	100	5.764	0.195	11.57	2.199	2.893	6.459
2009	Jun	4,320	100	5.826	0.353	13.46	2.249	2.827	6.542
2009	Jul	4,464	100	6.377	1.025	15.47	1.930	3.636	7.063
2009	Aug	4,464	100	6.310	0.009	10.84	2.005	3.660	6.991
2009	Sep	4,320	100	5.269	0.347	11.47	1.981	2.916	5.914
2009	Oct	4,464	100	3.415	0.042	9.35	2.032	1.757	3.847
2009	Nov	4,320	100	3.632	0.111	14.9	2.416	1.641	4.088
2009	Dec	4,032	90.3	3.236	0.301	10.17	1.464	2.340	3.657
2010	Jan	4,176	93.5	3.051	0.140	10.16	1.475	2.204	3.455
2010	Feb	4,032	100	3.876	0.231	11.28	2.148	1.905	4.381
2010	Mar	4,464	100	4.644	0.041	11.38	2.370	2.055	5.241
2010	Apr	3,312	100	5.432	0.155	12.51	2.644	2.175	6.133

Table 9: Monthly wind speed at 10m height (agl) for Hawksbay Mast.

Keti Bandar

Site Description

The town of Keti-Bandar is 100 km south-east of Karachi city. AEDB-UNDP(WEP) Keti-Bandar wind measuring mast site is located in the outskirts of Keti Bandar. The geodetic location of mast is of the mast is 2.4^0 11' 49.18"N 67^0 37'38.67"E. This 85 m high wind measuring the mast is of lattice structure with triangular cross section. During the site visit, mast was found in good condition and the installation arrangement of sensors was in compliance with the IEC 61400-12-1 Standards [2] for collecting bankable wind data. The working of all the installed sensors was checked from the logger and the correlation coefficients from the MEASNET certificates for recording the wind data were verified.

The installation arrangement of sensors can be seen in Figure 20 given below. The site is wide open flat agricultural land having surface roughness of class 2.89 with surface roughness of 0.291m. The mast site has no major wind breakers in the predominant direction of wind (west). However, the presence of many trees in the southeast and dense field may cause disturbance in wind measurements at low level (10m). Panoramic view of the mast site is given in Figure 21.

This site can easily accommodate future wind energy development in the Keti-Bandar region. Big acreage of Government land is available in the proximity which can be used for development purposes. Two grid stations are in the proximity of Keti Bandar region where the load may be dispersed. At present Keti-Bandar area is connected with the Laadiun grid station as the Mirpur Sakro grid is feeble in comparison with Laadiun grid station.

Figure 19: AEDB-UNDP (WEP) Keti-Bandar Mast.

Figure 20: Installation Arrangement of Sensors at Keti-Bandar Mast

Figure 21: Panoramic View of Keti-Bandar Mast.

Site Data Analysis

The 85 m mast started collecting wind data in February 2009. Hence the time series available for the data analysis of this mast is of 14.5 months (February 12, 2009- April 28, 2010). Wind shear profile based on the available data is presented in Figure 22 with the measured data in green dots at different levels above ground. The calculated power law exponent is 0.221 which can be used to calculate the wind shear profile at any height.

The wind data recoded at 10, 30, 60 and 85 m heights has been analyzed to determine the monthly mean wind speeds. The results are shown in Figure 24 and Tables 10-13. The mean annual wind speed is 6.9 m/s, and the average Weibull shape factor (k) is 3.6. Figure 23 shows the wind rose, or wind direction frequency, of Keti-Bandar mast for the fourteen month period. It can be seen that the most dominant direction of wind at this mast site is west.

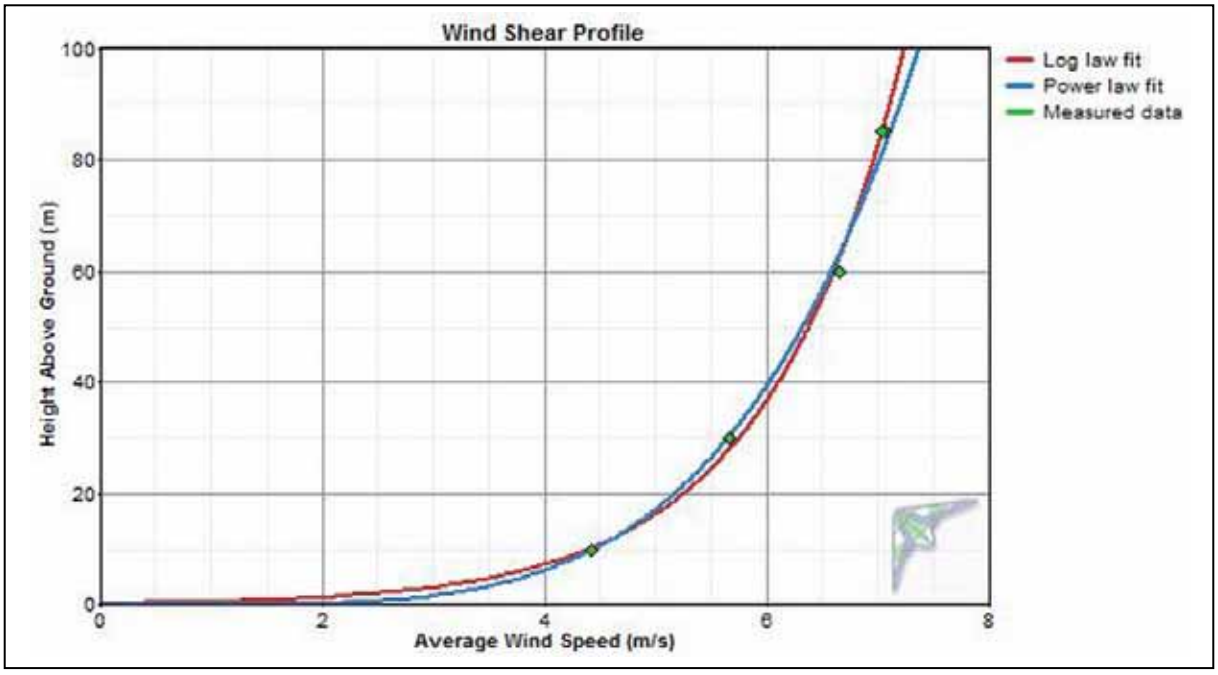

Figure 22: Wind Shear profile for Keti-Bandar Mast.

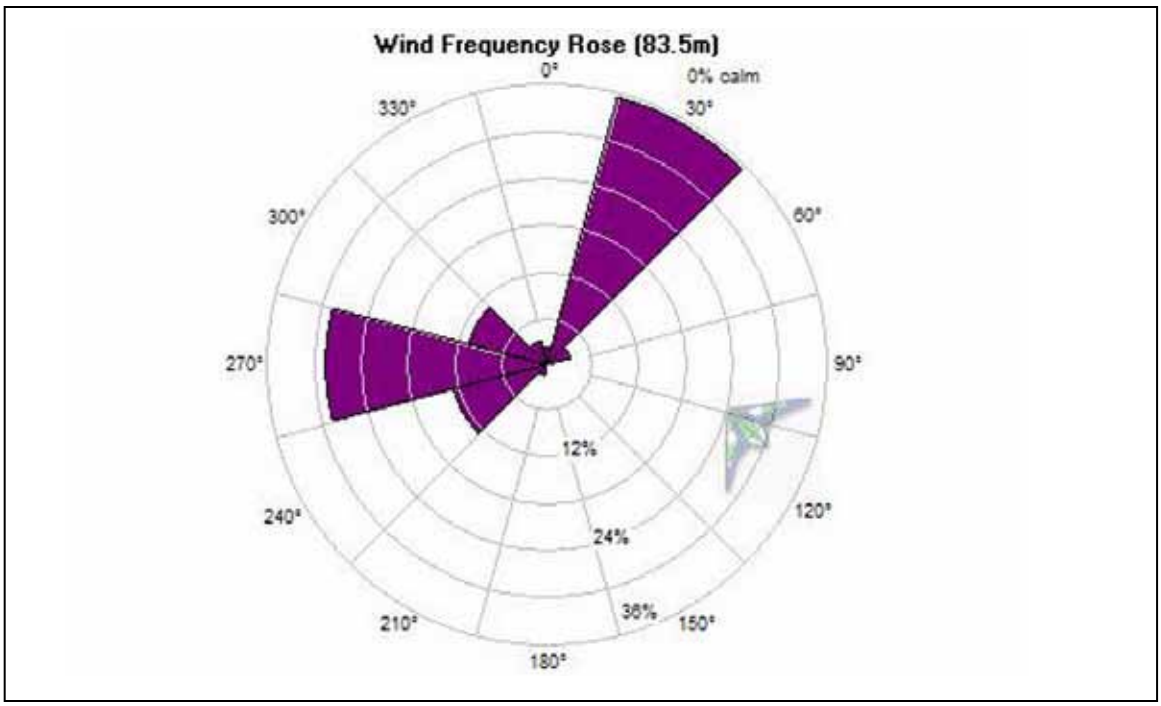

Figure 23: Wind Direction Frequency Distribution for Keti-Bandar Mast.

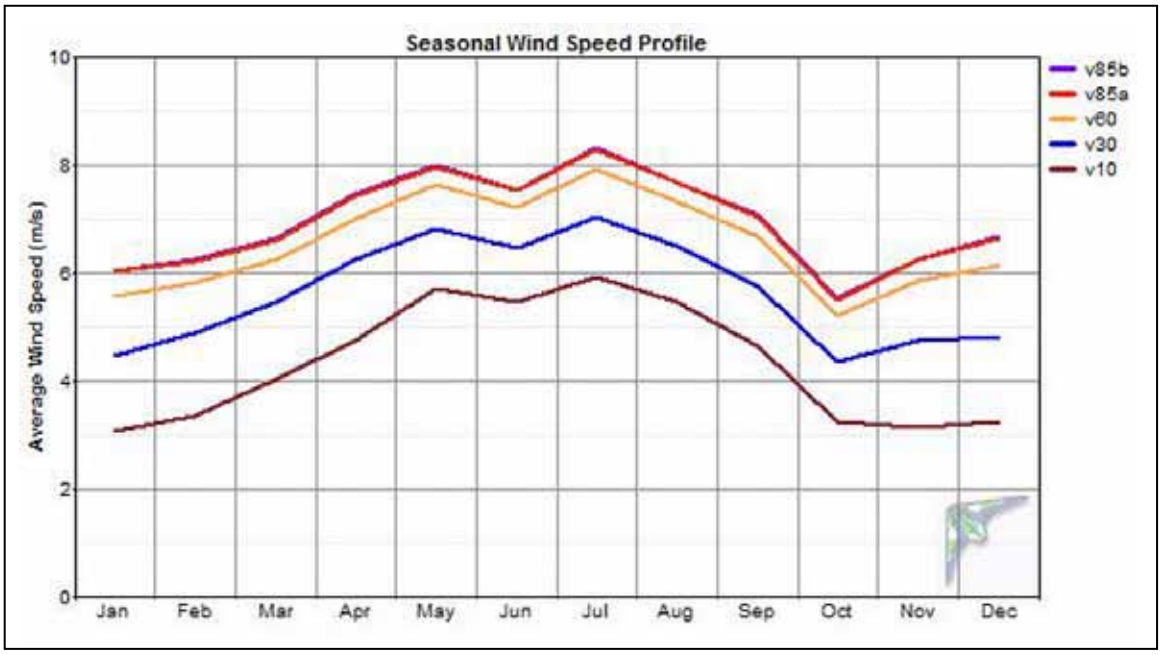

Figure 24: Wind Speed Seasonal profile for Keti-Bandar Mast.

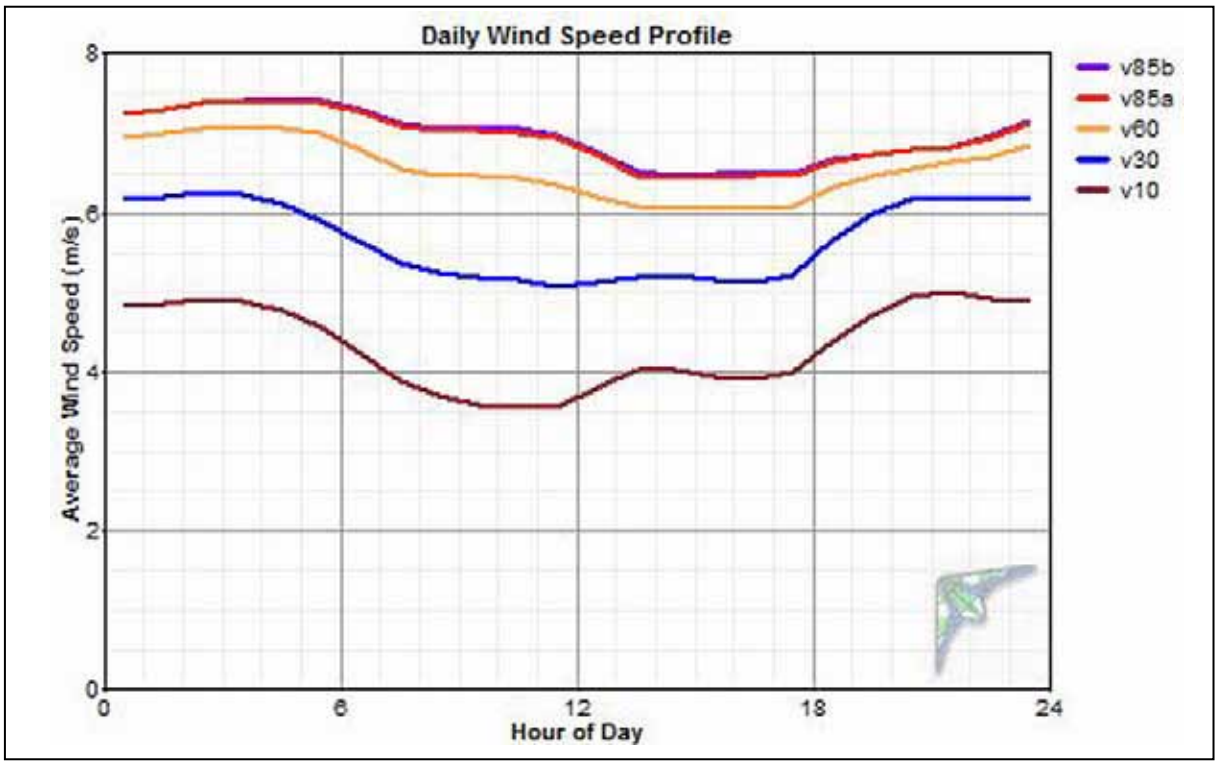

Figure 25: Diurnal Wind Speed profile for Keti-Bandar Mast.

The diurnal pattern (Figure 25) of wind speed at the mast site shows that wind speed at this site increases after dusk, remains high until dawn and is lowest in the evening.

Based on the analysis of wind data gathered from Keti-Bandar mast for the period of 14.5 months (from February 2009 to April 2010) the mean, minimum and maximum temperatures of this site at 85 m height are 22.6, 12.3 and 38.3˚C respectively. At 85m height, the mean power density is 178 W/m^2 and mean turbulence intensity is 0.086. The monthly mean wind speeds recorded along with data acquisition ratio at different levels (agl) are shown in Tables 10-13.

85m Level									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2009	Feb	2,402	100	5.914	0.557	11.60	1.999	3.232	6.59
2009	Mar	4,464	100	6.336	0.777	12.33	1.997	3.509	7.024
2009	Apr	4,320	100	7.084	0.622	14.17	1.942	4.104	7.794
2009	May	4,464	100	7.994	1.480	13.48	1.920	4.738	8.720
2009	Jun	4,320	100	7.545	0.748	13.96	2.323	3.684	8.365
2009	Jul	4,464	100	8.307	1.338	20.94	2.217	4.087	9.142
2009	Aug	4,464	100	7.685	1.193	13.30	1.991	4.404	8.425
2009	Sep	4,320	100	7.068	2.197	13.21	1.711	4.459	7.733
2009	Oct	4,378	98.1	5.516	0.686	13.15	1.791	3.199	6.134
2009	Nov	4,318	100	6.269	0.326	15.57	2.664	2.525	7.078
2009	Dec	4,430	99.2	6.671	0.452	15.02	2.843	2.536	7.526
2010	Jan	4,407	98.7	6.059	0.672	12.88	2.551	2.552	6.836
2010	Feb	4,032	100	6.438	0.356	13.09	2.401	2.878	7.215
2010	Mar	4,461	99.9	6.936	1.456	12.18	1.827	4.307	7.623
2010	Apr	3,929	100	7.850	1.269	14.21	2.042	4.187	8.622

Table 10: Monthly wind speed records at 85m height (agl) for Keti-Bandar Mast.

60m Level									
Year	Month	Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2009	Feb	2,402	100	5.546	0.447	11.06	1.854	3.291	6.178
2009	Mar	4,464	100	5.972	0	11.6	1.83	3.663	6.61
2009	Apr	4,320	100	6.66	0.656	13.86	1.857	3.95	7.339
2009	May	4,464	100	7.648	1.447	13.31	1.943	4.422	8.383
2009	Jun	4,320	100	7.243	0.492	13.43	2.342	3.476	8.057
2009	Jul	4,464	100	7.936	1.306	19.94	2.206	3.916	8.758
2009	Aug	4,464	100	7.338	1.107	13.06	2.014	4.11	8.078
2009	Sep	4,320	100	6.688	2.051	13.01	1.737	4.127	7.353
2009	Oct	4,378	98.1	5.222	0.312	10.78	1.656	3.356	5.8
2009	Nov	4,318	100	5.871	0.229	15.04	2.288	2.763	6.601
2009	Dec	4,430	99.2	6.144	0	12.44	2.333	2.908	6.895
2010	Jan	4,407	98.7	5.606	0.297	11.33	2.149	2.85	6.297
2010	Feb	4,032	100	6.012	0.019	12.46	2.071	3.167	6.71
2010	Mar	4,461	99.9	6.533	1.439	11.94	1.763	4.13	7.194
2010	Apr	3,929	100	7.431	1.149	14.05	2.051	3.895	8.195

Table 11: Monthly wind speed records at 60m height (agl) for Keti-Bandar Mast.

30m Level									
Year	Month	Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2009	Feb	0	0	0	0	0	0	2	0
2009	Mar	0	0	0	0	0	0	2	0
2009	Apr	1,396	32.3	5.857	1.207	13.09	1.813	3.417	6.508
2009	May	4,464	100	6.829	1.357	12.44	2.021	3.772	7.563
2009	Jun	4,320	100	6.473	0.356	12.6	2.346	3.069	7.248
2009	Jul	4,464	100	7.067	1.213	17.21	2.145	3.595	7.84
2009	Aug	4,464	100	6.532	0.939	12.25	2.029	3.595	7.248
2009	Sep	4,320	100	5.761	1.571	12.04	1.847	3.395	6.418
2009	Oct	4,378	98.1	4.368	0.246	9.77	1.468	3.158	4.868
2009	Nov	4,318	100	4.769	0.001	13.48	1.637	3.063	5.321
2009	Dec	4,430	99.2	4.845	0.041	9.66	1.484	3.75	5.363
2010	Jan	4,407	98.7	4.492	0.05	10.15	1.549	3.248	5.012
2010	Feb	4,032	100	4.915	0.272	11.53	1.584	3.326	5.467
2010	Mar	4,461	99.9	5.495	1.174	11.35	1.745	3.383	6.119
2010	Apr	3,929	100	6.401	1.125	13.26	2.153	3.198	7.147

Table 12: Monthly wind speed records at 30m height (agl) for Keti-Bandar Mast.

10m Level									
Year	**Month**	**Records**	**Recovery** Rate (%)	**Mean** (m/s)	**Min** (m/s)	**Max** (m/s)	**Std. Dev.** (m/s)	**Weibull k**	**Weibull c** (m/s)
2009	Feb	2,402	100	3.159	0.279	9.1	1.48	2.256	3.573
2009	Mar	4,464	100	3.824	0.478	9.35	1.615	2.537	4.315
2009	Apr	4,320	100	4.417	0.357	11.19	1.889	2.513	4.989
2009	May	4,464	100	5.73	0.657	10.47	1.945	3.321	6.399
2009	Jun	4,320	100	5.492	0.413	10.65	2.136	2.853	6.169
2009	Jul	4,464	100	5.939	0.81	13.51	1.874	3.491	6.602
2009	Aug	4,464	100	5.477	0.618	10.5	1.822	3.367	6.1
2009	Sep	4,320	100	4.661	0.95	9.77	1.792	2.871	5.24
2009	Oct	4,378	98.1	3.274	0.015	8.27	1.45	2.41	3.7
2009	Nov	4,318	100	3.172	0.273	10.65	1.365	1.463	3.299
2009	Dec	4,430	99.2	3.251	0.354	7.75	1.18	2.9	3.641
2010	Jan	4,407	98.7	3.107	0	8.27	1.311	2.522	3.5
2010	Feb	4,032	100	3.489	0.05	9.97	1.522	2.435	3.942
2010	Mar	4,461	99.9	4.251	0.364	9.47	1.826	2.515	4.807
2010	Apr	3,929	100	5.125	0.771	11.23	2.157	2.584	5.786

Table 13: Monthly wind speed records at 10m height (agl) for Keti-Bandar Mast.

Comparison of Sites

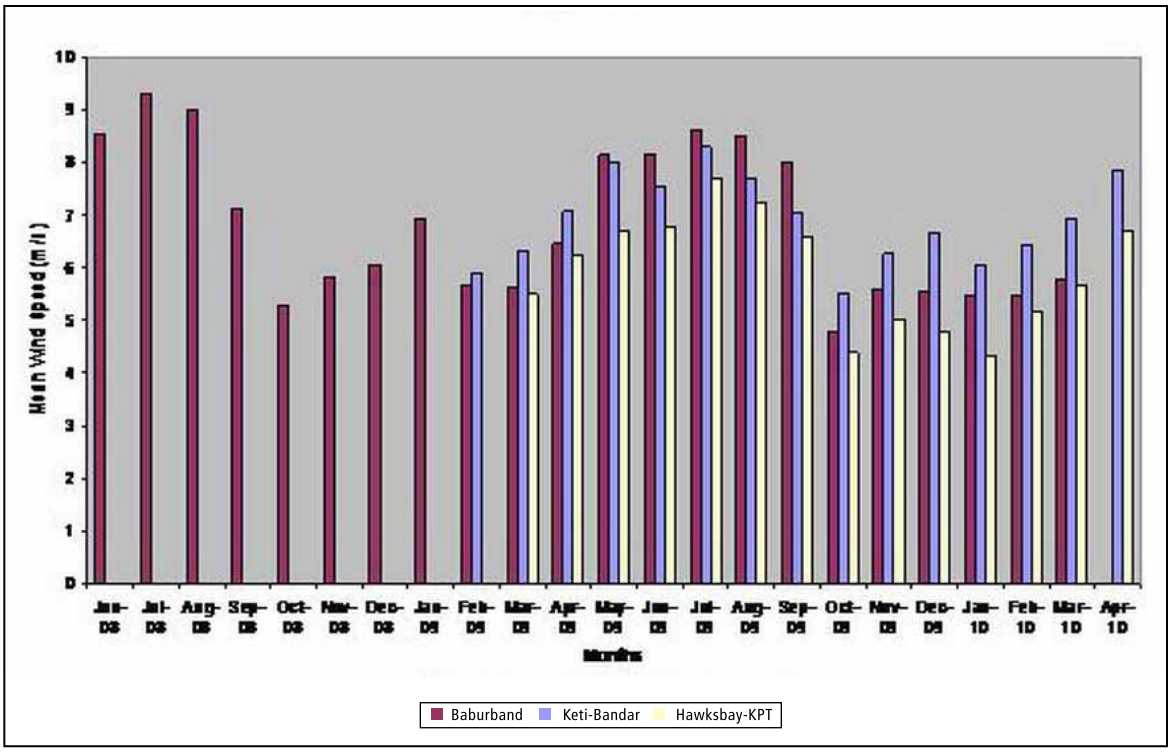

Fig.26: Comparison of AEDB - UNDP (WEP) Mast sites in Gharo-Keti Bandar Wind Corridor

Conclusion

The wind data obtained from the three sites namely Baburband, Keti Bandar and Hawksbay-KPT was analyzed. The results of the analyses indicates that the annual mean of mean wind speeds at 80 m height for these sites are:

	Mean Annual Speed	Weibull shape factor (k)
Baburband	7.1 m/s	2.6
Keti Bandar	6.9 m/s	3.6
Hawksbay-KPT	5.9 m/s	3.23

A comparison of the wind potential of the three sites yields the following.

- **Baburband** site is the highest potential wind area in comparison with the other two sites. Its annual average wind speed at 80 m height from ground is 7.1 m/s. The shape factor (k) of the Weibull distribution for the site data is 2.6; this indicates that the distribution is relatively close to the mean value which ensures high production efficiency.
- **Keti-Bandar** site is also a high potential area; it has the annual average wind speed at 80 m height from ground of 6.87 m/s. Practical experience and analysis of the site suggest that Keti Bandar site could achieve the long term annual average wind speed of around 7.0 m/s. The shape factor (k) of the Weibull distribution for the site data is 3.6, indicating that the distribution is close to the mean value which ensures high production efficiency.
- **Hawksbay-KPT** site has the lowest potential for wind energy in comparison with the other two sites. It has an annual average wind speed at 80 m height from ground of 5.9 m/s. The shape factor (k) of the Weibull distribution for the site data is 3.23, indicating that the distribution is not dispersed which improves the production value at this wind speed.

Bibliography

[1] World Wind Energy Report 2009, World Wind Energy Association, accessed August 2010.

[2] International Standard IEC 61400-12-1, Power Performance Measurements of Electricity Producing Wind Turbines Part 12-1, IEC Edition 1, 2005.

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