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FEASIBILITY OF CLEAN ENERGY FROM WIND OVER EGYPT

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Abstract- A project for wind atlas of Egypt has been established among Risø National Laboratory of Denmark, the Egyptian Meteorological Authority (EMA), and New and Renewable Energy Authority (NREA). The work is now going on to finish the last component of the project.

Preliminary investigations have been made here for modeling wind climate and estimation of available power density from wind. To do so, hourly data of wind speed and direction in the period 1981-1995 at 25 surface meteorological stations have been used to depict climate features of wind over Egypt. It was found that mean annual wind speed ranged from 2 m. /sec to 7.5 m. /sec with maximum centers at Port Said, Hurghada, Ras Benass, Elowainat, and around Nasser lake. Centers of minimum speeds have been found at Siwa, El-Arish, and Luxor.

Estimations of power density of wind have indicated that promising areas of wind energy are located at Port Said, Hurghada, Ras Benass, and around Nasser Lake. At some places, maximum available wind energy at 50 meters above ground level has culminated to 3114 watt m^{-2} . As a result, Port Said, Hurghada, Ras Benass, adjacent areas to Nasser lake, and Elowainat are the most suitable regions over Egypt to erect wind farms.

It is suggested that the Egyptian policy makers have to plan to introduce wind-turbine industry in Egypt. This will manage users to get clean energy from wind at low costs, which encourage them to replace the conventional energy resources with clean energy ones.

1. INTRODUCTION

The first sign of getting energy from wind has been found in Fares since 200 BC. This was mentioned in the Arab Book, where a description of an elementary windmill was given by Flavin (1981)]. In China, windmills were used in the 7th century to grind grains. In Denmark where there was a lack in fossil fuel resources, a great number of windmills were used in 1900 to supply Denmark with 25% of its demand from energy (Frank, 1980). It is estimated that there are over million wind pumps that are being used in Argentina, and USA. The water that elevated by these pumps is used for houses and cattle (Darraw, 1981).

In the first decade of this century, many countries around the world will manage to obtain 20% to 30% of its electricity from wind resources (Flavin, 1981). It is estimated that 2% of solar energy that enter the earth's atmosphere is transformed to kinetic energy that derive the wind around the globe (Gustavin, 1979). Recently, the importance of getting energy from wind has increased since the urgent need to change energy supplier from polluted resource to clean one. This has been done to face the problem of climate change and its impact on the environment.

The energy from wind is a preferable resource among other resources. The possible energy from wind is higher than that could be obtained from the sun because it blows by day and night (PNL, 1990). For all these foregoing reasons, the manufacture of wind turbines has been developed significantly in recent years. The best wind turbine that is being sold today in the market can produce electricity at a rate of only 5% per kilowatt-hour (Bollier, 1980).

In spite of all foregoing advantages from using wind as energy source, there are some disadvantages from using wind turbines in wind farms. This is produced from erecting turbines on land of high area and at coastal area where the nice scenery of the nature is masked. Besides, wind turbines cause noise and interference of radio waves especially when blades of turbines are made from metals Sengapupta (1978). In addition, the safety factor is decreased in the zone of the wind farm especially when turbines are erected in the route of migrating birds around the world.

The features of climate of Egypt have been described in many works and textbooks, among them, the work of Griffiths and Soliman (1972). They described distribution of many meteorological elements. They found maximum annual wind speeds of order 5.6 ms^{-1} at coastal areas either on Red Sea or on north coast of Mediterranean. In Delta and interior areas, the speed decreases gradually towards Western Desert where it ranges from 3.36 to 1.68 ms^{-1}.

Elliott *et al*. (1987) has estimated distribution of annual average wind power near earth's surface over Egypt. Classifying wind speeds into three classes, they found that the energy density ranged from 200 to 400 Watt.m^{-2} with higher values over Coastal areas and west of Nasser Lake.

Mortensen and Said (1996) have issued Wind Atlas of Gulf of Suez. They have modeled wind data over the Gulf of Suez in the period 1991-1995 by using WAsP program package issued by Danish laboratory of Mortensen *et* *al.* (1998). They gave a description of the Gulf wind climate and possible wind Energy available in this area. They found that Hurghada area is a promising resource of Wind Energy. However, the short period of the study and its limitation to Gulf of Suez does not give a complete picture about wind available over the whole area of Egypt.

Distributions of mean wind vector as well as persistence are important factors to describe wind climate over Egypt. The persistence ratio may give an idea about the prevailing wind at a specified area. It is calculated as the ratio of mean modulus of wind vector to the mean wind speed at the same location and in the same period. So, it ranges from 0 to 1. When its value is near to 1, the wind blows from the same direction all the time and vise versa. Its distribution is useful in airport planning and environmental studies.

In this work, we will give a concise about what has been encompassed in the project of Wind Atlas of Egypt by the Egyptian Meteorological Authority (EMA), New and Renewable Energy Authority (NREA), and RisØ National Laboratory of Denmark. The project is composed of three components A, B, and C. The component A has been done by NEREA. EMA is responsible for executing component B. The component B will come to an end by October 2000. The component C will begin in March 2001. However, the project organization and components are depicted in Figures 1 and 2 respectively. Also, the remaining tasks of time plan of the project will be given. In addition, the general feature of wind climate and a rough estimate of available energy density from wind will be investigated. The computations of the variables at the 25 stations has been encompassed by FORTRAN programming by the authors as well as by the aid of Wind Atlas Analysis and Application Program (WAsP, 2000) .

Station name	Num	Latitude	Longitude.	X psition	Y position	st.Hei	Anomh
Units		0 ' "	0 ' "	meter-E	meters-N	meter	meter
.Sallum	300	31 33 60.00	25 07 60.00	322837.2	3493968.8	006.	09.
Mersa_Matruh	306	31 19 60.00	27 12 60.00	520612.9	3466616.4	028.3	06.
Alexandria	318	31 11 7.00	29 57 10.00	781413.9	3453943.7	006.8	09.5
Baltim	325	31 33 0.00	31 04 60.00	318058.6	3492203.1	002.2	09.
El-Gamil	332	31 16 48.00	32 14 34.00	427919.0	3460932.4	006.1	07.
El_Arish	337	31 04 55.00	33 49 39.00	578935.2	3439028.7	031.2	08.5
Cairo-Airport	366	30 08 5.00	31 24 5.00	346009.7	3334841.1	074.5	09.5
Minya	387	28 05 37.00	30 44 6.00	277450.3	3109688.3	040.5	17.5
Asyut	393	27 03 17.00	31 00 37.00	302653.2	2994096.8	069.6	18.6
Luxor	405	25 40 7.00	32 41 54.00	469724.3	2839058.6	088.4	10.
Asswan	414	23 58 14.00	32 49 17.00	481828.4	2651013.3	194.5	06.
Siwa	417	29 11 28.00	25 31 9.00	356018.4	3230113.4	-13.5	10.
Baharia	420	28 20 2.00	28 52 11.00	683291.9	3135654.0	129.5	08.
Shark_El_Ouinat	425	22 27 37.00	28 41 55.00	674786.1	2484797.0	270.75	10.
Dakhla	432	25 30 5.00	28 58 13.00	698038.8	2821972.4	111.7	14.4
kharga	435	25 27 3.00	30 32 0.00	251946.3	2817203.1	072.8	11.5
Abu_Swair	438	30 33 60.00	32 06 5.00	413822.2	3381972.7	016.	14.
Ismailia	440	30 35 33.00	32 14 53.00	427907.3	3384732.6	012.7	09.5
El_Malease	445	30 23 52.00	33 09 19.00	514916.7	3362923.2	320.20	09.5
EL_Suez	450	29 52 28.00	32 28 19.00	449003.7	3305038.0	003.6	10.
Saint_Cathrene	457	28 40 48.00	34 03 29.00	603377.9	3173036.5	1350.0	10.
Sharm_EL_Sheikh	460	27 58 18.00	34 22 58.00	636007.0	3094877.2	051.00	10.
Hurghada	463	27 11 5.00	33 48 8.00	579467.0	3007191.2	014.1	09.
Kosseir	465	26 06 32.00	34 16 49.00	628020.8	2888411.7	010.80	10.
Ras-Benas	475	23 57 49.00	35 28 28.00	751812.4	2652442.4	004.6	10.

Table: 1 Set of meteorological stations introduced in the study

2 - DATA AND METHODOLOGY

Raw data of wind speed and direction at Universal Time (UT) 00, 03, 06, 09, 12, 15, 18, 21 in the period 1981-1995 have been used in this study. To represent all different localities in Egypt, 25 surface meteorological stations among the EMA network have been introduced in the study (Table, 1). The stations have been chosen carefully such that records are continuous and missing data are least as possible as they could be. According to WMO regulations of measuring wind, all wind anemometer height at all stations is 10 meters above ground level. So, no corrections were made and we have regarded the data were homogeneous.

To estimate persistence at a given station, the method of Panofsky and Brier (1958) has been used. So, if S_{kj} is the value of wind speed (regardless direction), V_{kj} is the wind vector at observation of index k and at station of index j, then the persistence P_k is determined from the relation:

$$P_k = \frac{\left|\overrightarrow{V_{kj}}\right|}{\frac{1}{n}\sum_{j=1}^{j=n} S_{kj}} \qquad k = 1,......,25 \quad \& \; j = 1,......,n \qquad (1)$$

Where n is the number of observations in the whole period.

To estimate average wind power, the output of scale parameter A and the shape parameter K at each station (Weibull, 1951) have been used. A rough estimate of wind power E_j and available maximum wind power density P_j at 50 meters level above ground at each station of index j has been estimated from the relations:

$$E_j = \frac{1}{2}\rho A_j^3 \Gamma\left(1.0 + \frac{3.0}{k_j}\right) \qquad : j = 1,2,...,25 \qquad (2)$$

Where ρ is air density and Γ is the Gamma function that can be determined from the integration:

$$\Gamma(z) = \int_0^\infty x^{z-1} e^{-x} \, dx \qquad (3)$$

$$P_j = \frac{1}{2}\rho A^3 \left(\frac{K_j + 2}{K_j}\right)^{\frac{1}{K_j}} \qquad (4)$$

The men density ρ was regarded to be 1.23 kg m^{-3} . However, the EMA team has to visit the sites of meteorological stations to determine the roughness and obstacles around wind masts. These measurements are necessary for the model that estimates the effect of roughness, obstacles, and shelters on wind flow. A typical map for roughness and obstacles around wind mast at Aswan station can be seen in Figure 3.

3. RESULTS

figure 4 depicts annual distribution of mean wind speeds obtained from the data. From the Figure, it can be shown that mean speed ranges from 2.0 to 7.5 $m.s^{-1}$. Areas of maximum speeds are located at Gulf of Suez, Port Said, Ras benass, and around Nasser Lake. Areas of minimum speed are located at Delta, El-Arish, Luxor, and in western desert of Egypt around Siwa Oasis. The diurnal variation of wind speed in summer and winter at Ras

Benass can be seen in Figure 5. It can be seen that the wind speeds are higher in summer than those in winter. This may due to the high contrast between sea surface temperature and that of land in summer season.

The distribution of magnitude of annual wind vector looks like that of mean wind speed, but with fewer orders of magnitude. Also, it has been found that the magnitude of resultant vector ranges from 0.6 to 4.8 $m.s^{-1}$. Areas of maximum resultants are located at Gulf of Suez, at Port Said at Ras benass, and around Nasser Lake. Areas of minimum resultants are located at Delta, El-Arish, Luxor, and in Western desert of Egypt around Siwa oasis.

By applying equation (1), Annual distribution of persistence P_j was found to range from 25% to 70% Maximum persistence is located around Minya, Hurghada, Ras benass, and Zonal belt around Nasser Lake. On other hand, low persistence is found over Delta, El- Arish, Luxor, and Western Desert. This leads one to conclude that areas of high persistence such as that of south valley and around Nasser Lake are suitable sites to erect airports because of the steady wind direction in them. Besides, new towns planning in these areas could have better environmental impact when designer takes into consideration the persistence distribution in these areas.

Figure 6 depicts the mean wind speed in ms^{-1} , mean energy density, wind rose, and Weibull distribution for all sectors at Cairo Airport. WAsP package has been used to encompass computations. From the upper part of the figure, one can see that, at different roughness and different heights, the mean wind speed ranges from 2.7 $m.s^{-1}$ to 8.2 ms^{-1} and the mean energy density ranges from 26 to 525 Watt m^{-2} with maximum value at 200 meters level above the ground. Generally, wind speed and energy are higher at 200 meters height and roughness-class 0.000 m than at lower levels. The wind rose in lower left part of Figure 6 shows that the maximum frequency takes place in northwest to northeast direction. The Weibull distribution of wind is seen in the lower right part of the Figure. The scale parameter A equals to 6.5 ms^{-1} and the shape parameter K equals 2.18. The maximum expected wind speed was found to be 13.2 ms^{-1} at 10 meters above the ground. This has been used to compute the mean energy and maximum energy density at 50 meters above the ground at each station.

Distribution of mean energy density and the maximum available energy density at 50 meters above ground are depicted in Figure 7 and Figure 8. From Figure 7, one can see that mean energy density over Egypt at 50 meter above ground level ranges from 100 to 1200 $Watt.m^{-2}$. From figure 8, one can see that maximum available energy density over Egypt at 50 meter above ground level ranges from 400 to 2300 $Watt.m^{-2}$. It is clear that areas located around Hurghada, port Said, Rashness, and around Nasser Lake up to El- Owaynat are promising place where wind farms can be erected Around El-Arish, Luxor, and Siwa Oasis, the expected power from wind may not be economic where its value is less than 200 $Watt.m^{-2}$.

4. CONCLUSION AND RECOMMENDATIONS

From the above results, one can conclude that maximum wind speeds, magnitudes of wind vectors, and persistence are found mainly at coastal areas of Egypt and in the vicinity around Nasser Lake. In other parts of Egypt, these variables are relatively law.

The direction of major wind at coastal areas and North of Egypt is coming mainly from northwest to northeast direction. In further south of Egypt. it comes from southwest to northeast direction. In most sites nearby or at coastal areas. The wind speed culminates in summer season. This may be attributed to the effect of high contrast between Sea Surface Temperature and that of land in summer.

It was found that mean energy density from wind at 50 meters above ground level ranged from 100 $Watt.m^{-2}$ to 1200 $Watt.m^{-2}$. In the same time, maximum available energy density ranged from 200 $Watt.m^{-2}$ to 2300 $Watt.m^{-2}$ There are many promising areas in Egypt in which wind farms can be erected. These areas are located at Ras benass. Hurghada, Port Said, and around Nasser Lake up to Elowainat.

The results reported here were derived directly from measurements of wind speed and direction at the meteorological stations. These data are now being processed according to the wind atlas methodology. The wind atlas that will be published at the end of the project will contain details of data sets for each station. This will enable user to assess wind resources at different locations in Egypt accurately and in details.

As a result from the above conclusion one may recommend that the policy makers in Egypt have to plan to introduce wind-turbine industry in Egypt. This will manage users to get clean energy from wind at low costs, which encourage them to replace the conventional energy resources with clean energy ones.

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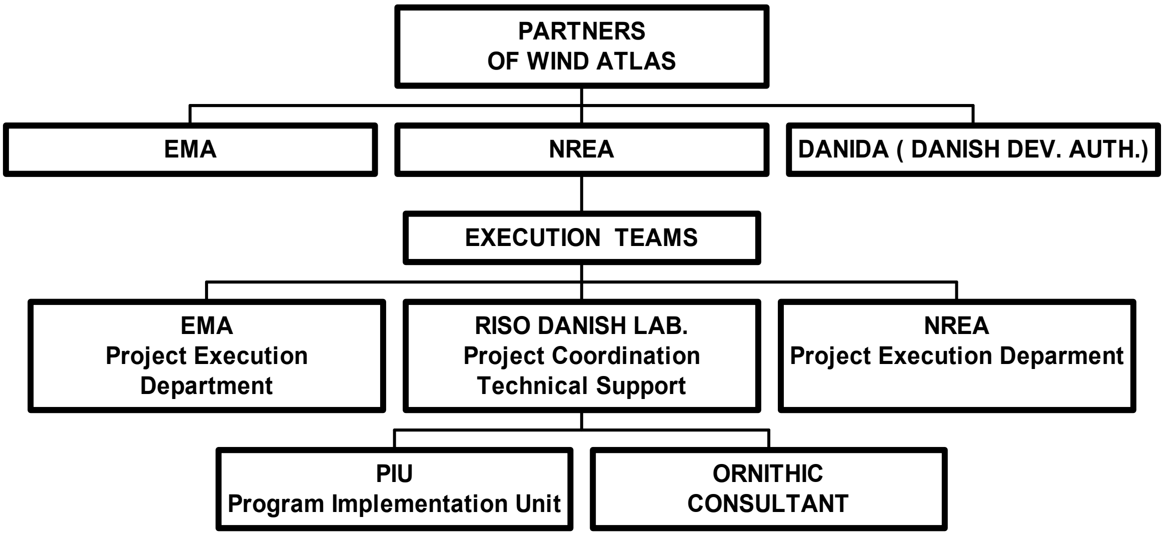

Fig. 1 Project Organization of Wind Atlas for Egypt

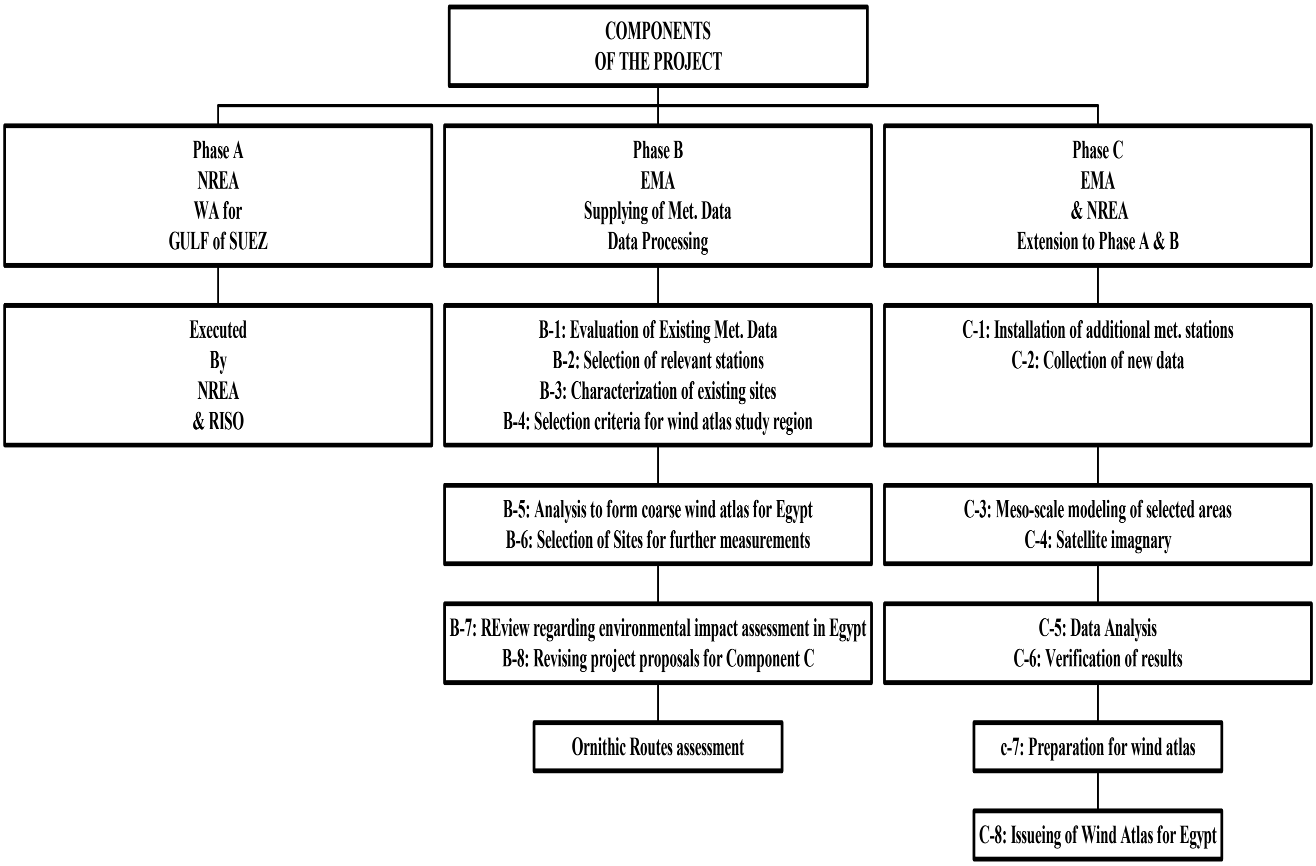

Fig. 2 Components of Project of Wind Atlas for Egypt

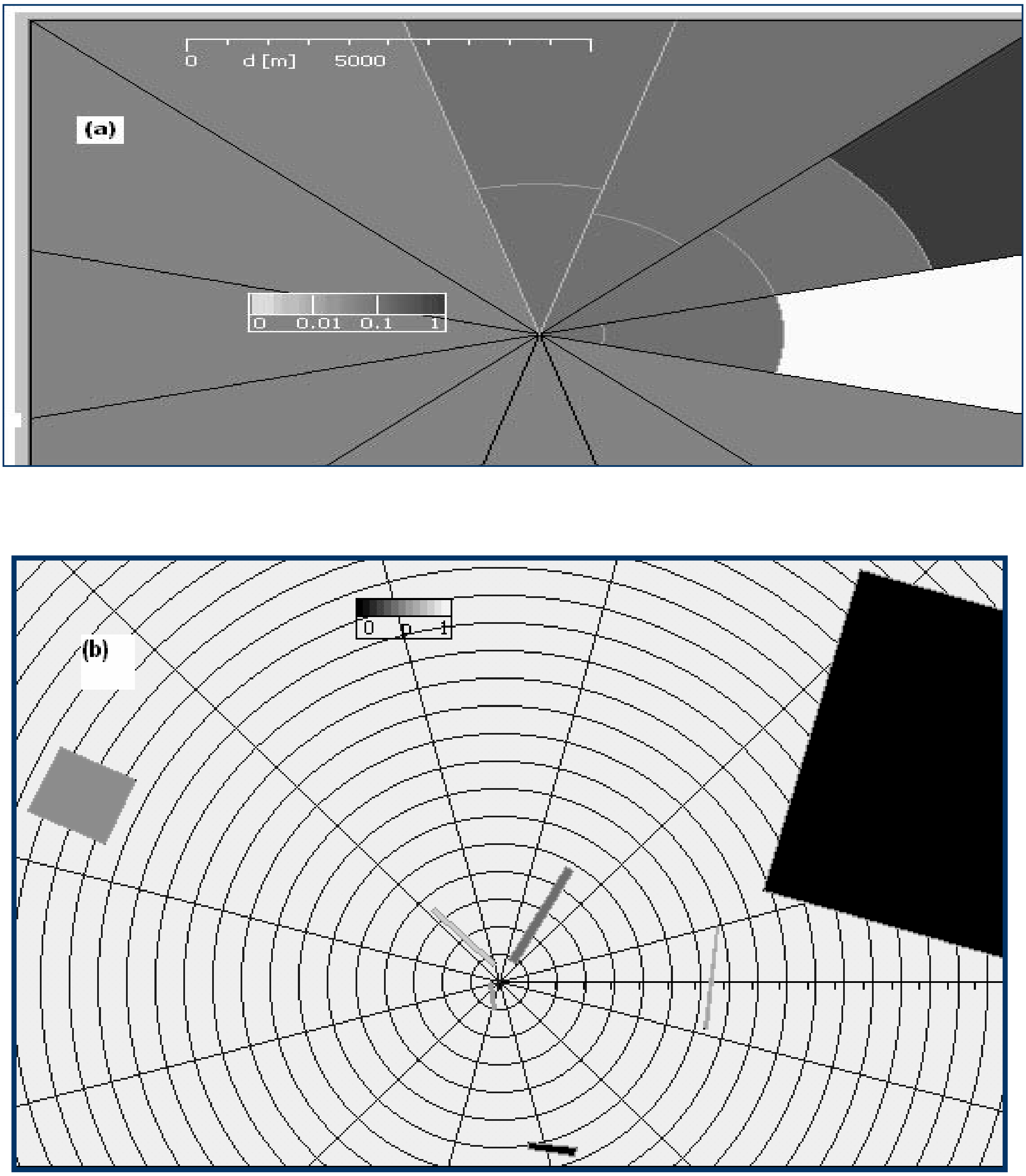

Fig. 3 Roughness map (a) and Obstacle map (b) at Aswan Wind Mast.

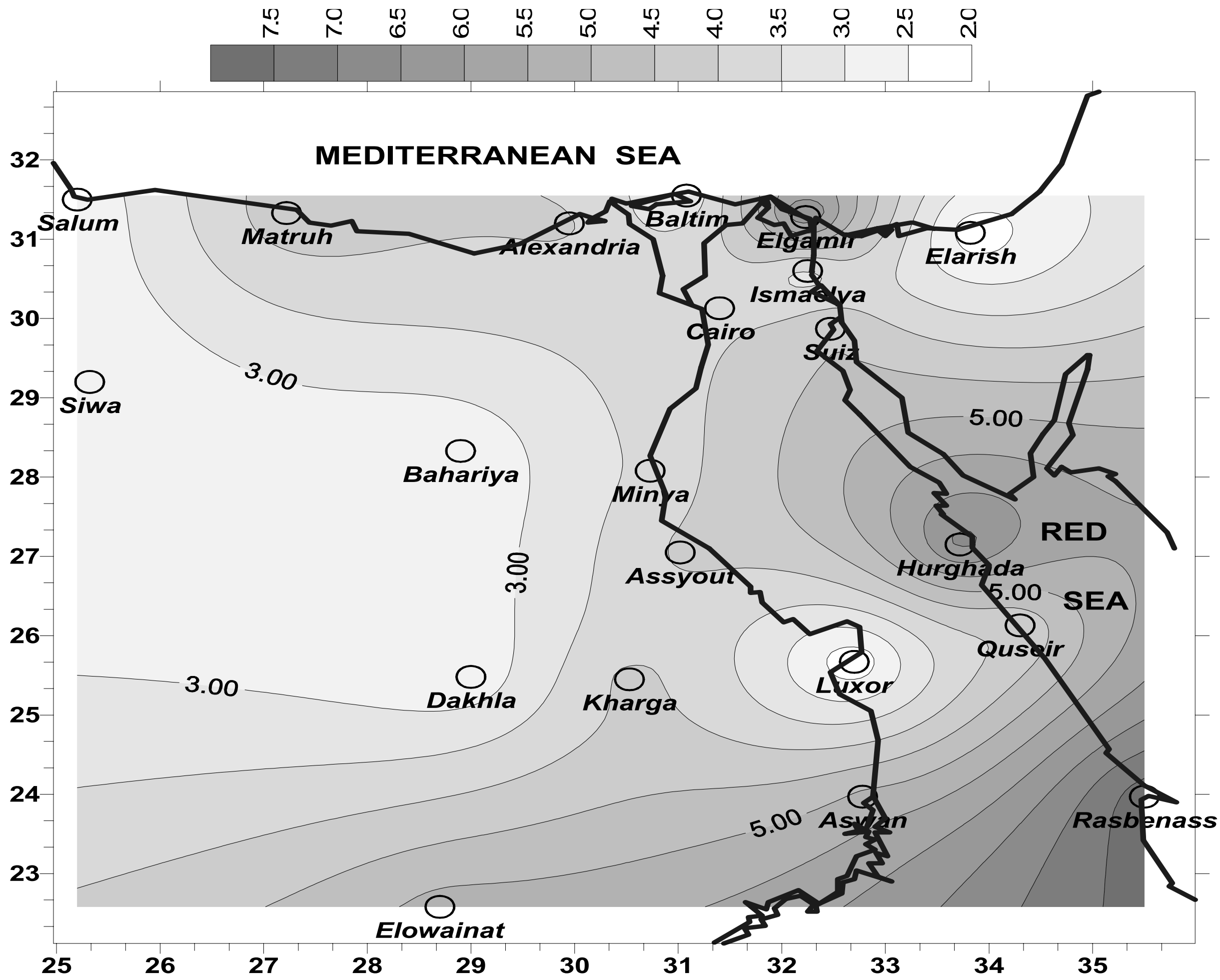

Fig. 4 Distribution of Annual Normals of Wind Speed (m./sec.)

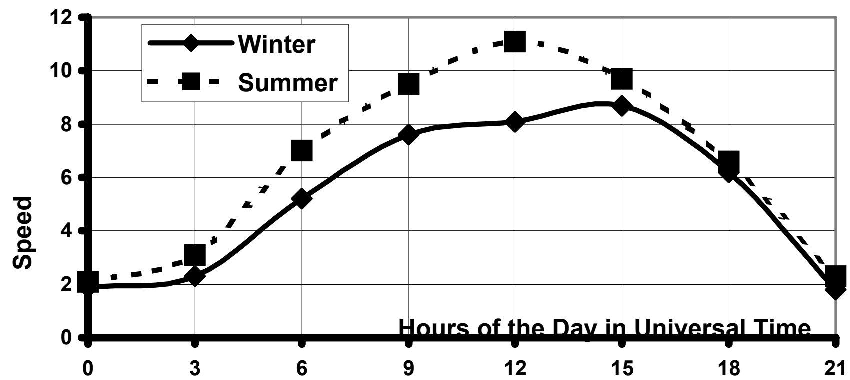

Fig. 5 Diurnal Variation of Wind Speed at Ras benass

		R-class 0 (0.000 m)	R-class 1 (0.030 m)	R-class 2 (0.100 m)	R-class 3 (0.400 m)
Height 1 (z = 10 m)	ms-1 Wm-2	5.8 208	4.0 82	3.5 54	2.7 26
Height 2 (z = 25 m)	ms-1 Wm-2	6.3 266	4.8 129	4.3 96	3.6 57
Height 3 (z = 50 m)	ms-1 Wm-2	6.8 323	5.5 181	5.1 141	4.4 92
Height 4 (z = 100 m)	ms-1 Wm-2	7.4 422	6.6 288	6.0 220	5.3 146
Height 5 (z = 200 m)	ms-1 Wm-2	8.1 595	8.2 571	7.4 427	6.4 273

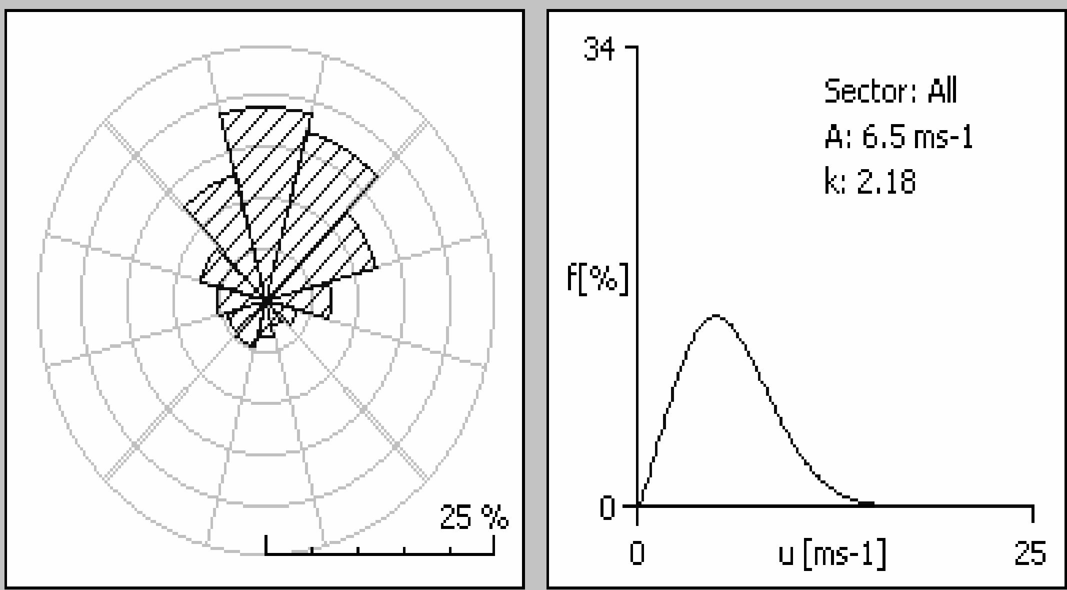

Fig. 6 Wind Atlas at Cairo Airport including mean wind speed and Energy density at 10 meters height (upper part), and Wind Rose (lower left part) and Weibull Distribution of all Sectors (lower right

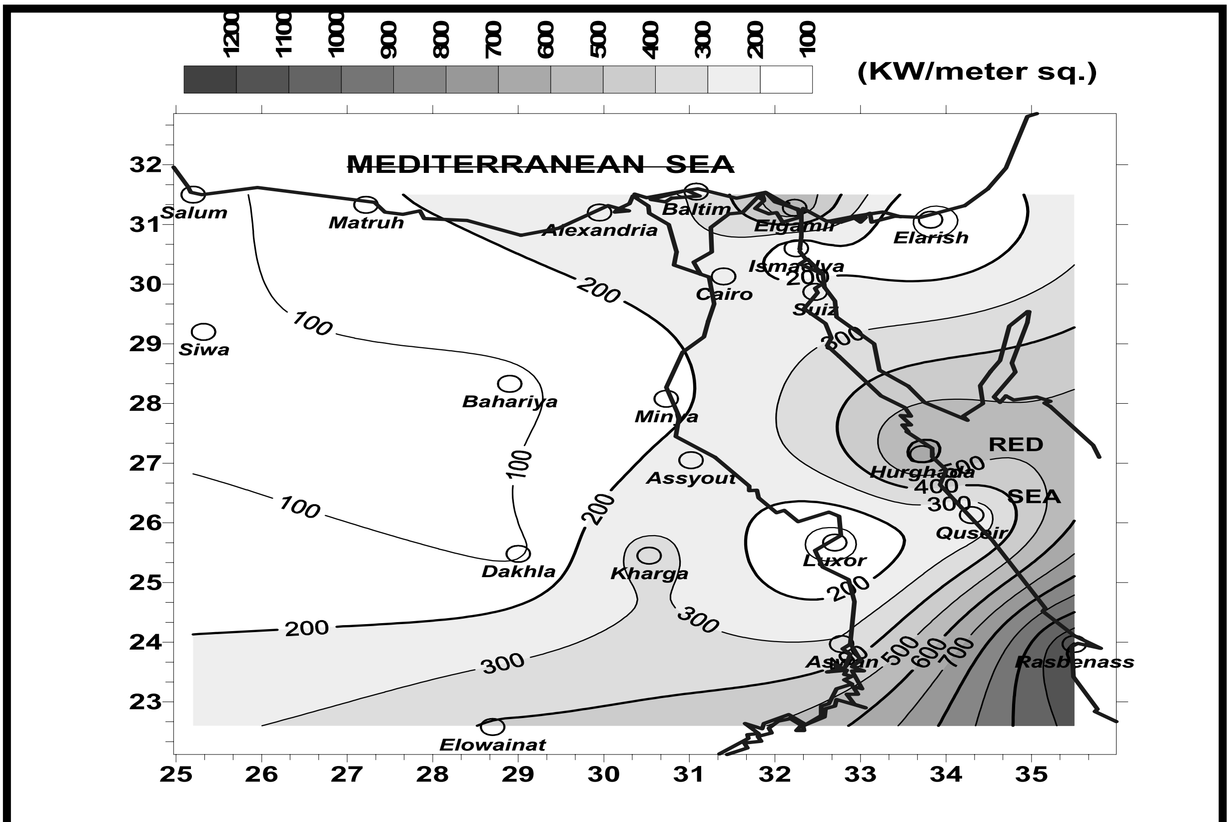

Fig. 7 Distribution of Mean Energy Density from Wind at 5o meters height.

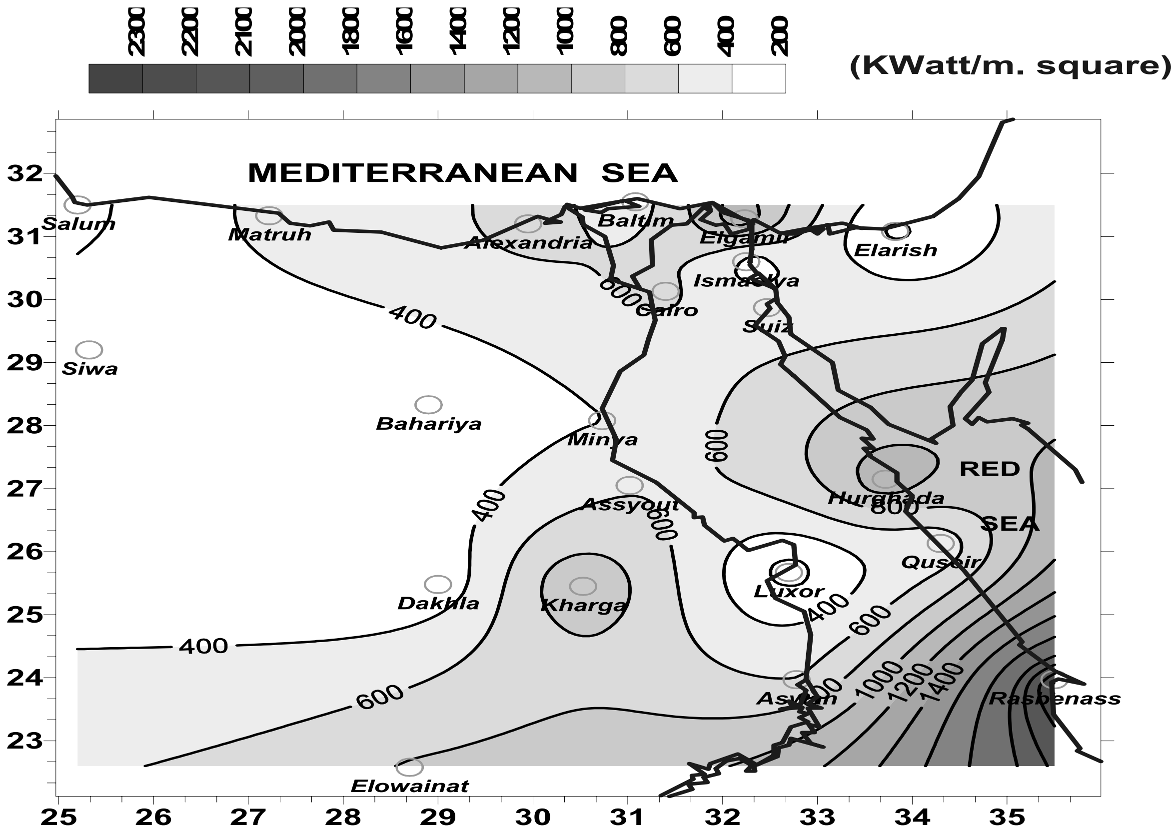

Fig. 8 Distribution of Maximum Avialable Energy Density at 50 m.

5- REFERENCES

Bollmeier, J., 1980: Small wind systems technology assessment, U.N. conference on new and renewable sources of energy.
Darraw, K., 1981: The use of wind power for pumping water, World watch Institute.
Elliott, D. L., D. S. Renne and K. Bassyouni, 1987: Wind Energy Resource Assessment of Egypt, *Proceedings of the sixth ASME Wind Energy Symposium*, Dallas, Texas, vol. 3, 215-216.
Flavin, C., 1981: Wind power is a turning point, World Watch Institute.
Frank, R. E., 1981: Wind Machine and use of wind power for pumping water, British Wind Energy.
Griffiths, J. F., and K. Soliman, 1972: The Northern Sahara Climate, *World Survey of Climatology*, vol. 10, 75-132, Elsevier, Amsterdam.
Gustavin, M. R., 1979: Limits to wind power utilization, Science, April 6,1979.
Mortensen, N. G., and U. S. Said, 1996: Climatological tables and Graphs for Wind Atlas Stations, *Wind Atlas for the Gulf of Suez,* Risø *National Laboratory*, Roskilde, Denmark, September 1996, 94 – 112.
Mortensen, N. G., L. Landberg, I. Troen, and E. I. Petersen, 1998: *Wind Atlas Analysis and Application Program* (WAsP), Vol. 1, Risø *National Laboratory*, Roskilde, Denmark.
Panofsky, H. A. and G. W. Brier, 1958: Frequency of vectors, Some *Applications of Statistics to Meteorology*, The Pennsylvania State University, University Press, 13 – 24.
PNL, (1990). Worldwide wind energy resource distribution estimates, Pacific North Laboratory.
Sengapupta, D. L. and Senior T.A.E., 1978: Electromagnetic Inference to TV Reception caused by Windmills, Third Workshop on Wind Energy, Washington D.C., May 1978.
WAsP, 2000: Wind Atlas Analysis and Application Program (WAsP, Version 7), RisØ National Laboratory, Roskilde, Denmark, February 2000.
Weibull, W., 1951: A statistical distribution function of wide applicability, *J. App. Mech.* 18, 293-297.