Solar and Wind Energy Potential Study of Lower Sindh, Pakistan for Power Generation

M. Akhlaque Ahmed, Sidra A. Shaikh, Maliha A. Siddiqui

Abstract**—**Global and diffuse solar radiation on horizontal surface of Lower Sindh, namely Karachi, Hyderabad, Nawabshah were carried out using sunshine hour data of the area to assess the feasibility of solar energy utilization for power generation in Sindh province. The results obtained show a large variation in the direct and diffuse component of solar radiation in summer and winter months in Lower Sindh (50% direct and 50% diffuse for Karachi and Hyderabad). In Nawabshah area, the contribution of diffuse solar radiation is low during the monsoon months, July and August. The K_T value of Nawabshah indicates a clear sky throughout almost the entire year. The percentage of diffuse radiation does not exceed more than 20%. In Nawabshah, the appearance of cloud is rare even during the monsoon months. The estimated values indicate that Nawabshah has high solar potential, whereas Karachi and Hyderabad have low solar potential. During the monsoon months the Lower part of Sindh can utilize the hybrid system with wind power. Near Karachi and Hyderabad, the wind speed ranges between 6.2 m/sec to 6.9 m/sec. A wind corridor exists near Karachi, Hyderabad, Gharo, Keti Bander and Shah Bander. The short fall of solar can be compensated by wind because in the monsoon months of July and August, wind speeds are higher in the Lower region of Sindh.

Keywords**—**Hybrid power system, power generation, solar and wind energy potential, Lower Sindh.

I. Introduction

SINDH is the south eastern province of Pakistan. Karachi, Hyderabad, Nawabshah, Hawksbay, Keti Bander and Shah Bander make up the Lower region of Sindh (Fig. 1 (a)). Karachi is the port city and Hawksbay seashore used as a picnic resort for Karachites. The province of Sindh is semi-arid and is in a good position to exploit renewable energy resources due to the abundance of sun and wind. A wind corridor also exits in Sindh province, with speeds ranging from 4.2 m/sec to 6.9 m/sec almost all year round.

Sindh is a high insulation province. It receives about 1KW of solar energy per square meter for 8 to10 hours on an average day (Fig. 1 (b)). The number of sunshine hours is equal to 3,000 to 4,000 hours per year.

In many Sindh villages, wood and animal dung are still used as fuel for cooking. This causes wide spread deforestation and women are also forced to walk many miles each day to gather wood. Moreover, their health suffers from the smoke emitted from cooking on wood fire. About 60% of the population lives in 40,000 villages located far away from the national grid. Connecting these villages to the national grid would be very costly, thus providing each home with solar panels would be cost efficient and would empower those communities economically and socially. Moreover, there is a shortfall of available power in the province of Sindh. Due to this deficit, the province of Sindh implements load sheading to prevent a shutdown of the entire system. In the province of Sindh, cities experience 06 hours of scheduled load sheading, while villages enforce 08 hours of load sheading. This shortfall of available energy effects business and industries, as well as the day to day lives of all communities in the province. Renewable resources can compensate for this shortfall.

Solar radiation data [1], [2] are essential as a fundamental input for solar energy applications such as photovoltaic and solar thermal systems. A detail analysis on the availability of solar radiation on horizontal surfaces is essential for the optimum design and study of solar potential. A number of empirical formulas have been developed to estimate the global and diffuse solar radiation using sunshine hour data [3], [4]. The method used to establish global solar radiation (H) is namely Sangeeta & Tiwari [5], [6]. In this the first order, the regression coefficient of Angstrom type correlation was used. Diffuse solar radiation was calculated using the Page and Liu and Jordan method [7], [8] The K_T (Cloudiness index) values are also calculated [9].

II. Methods of Prediction

The Angstrom equation relates to monthly-average daily irradiation H_0 to clear day irradiation H and the number of hours n of bright sunshine [10].

$$H/H_O = a + b\,(n/N) \tag{1}$$

where H is Global solar radiation and H_0 is Extraterrestrial radiation, ‘a’ and ‘b’ are the climatological determined regression constant, and n is the monthly mean daily number of sunshine hours, while N is the day length of the location.

Regression coefficients “a” and “b” have been obtained from the relationship given by [6]:

$$a = -0.110 + 0.235\,cos\Phi \;\; + 0.323\,(n/N) \tag{2a}$$

$$b = 1.449 - 0.553\,cos\Phi \;\; - 0.694\,(n/N) \tag{2b}$$

where φ is the declination angle and n/N is percentage of possible sunshine hours.

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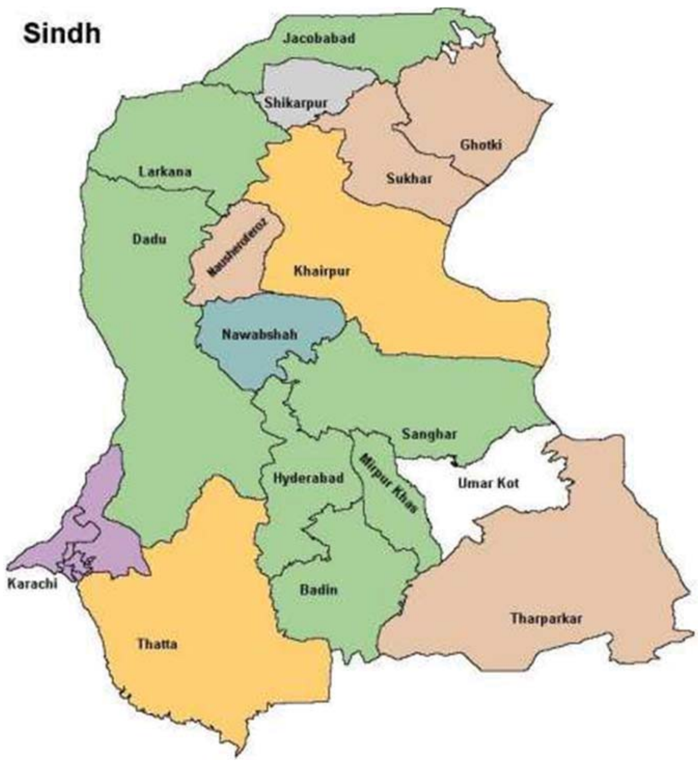
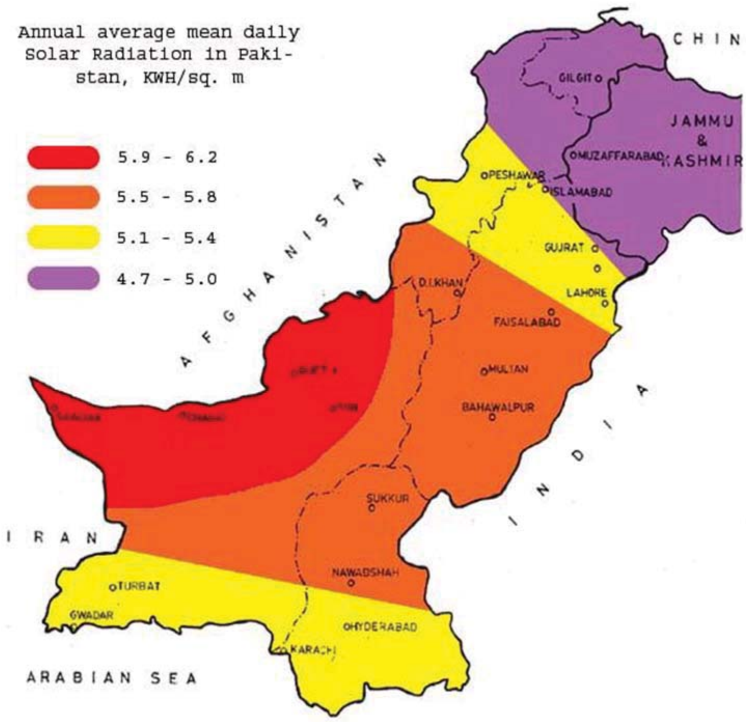
The mean monthly global solar radiation H for Karachi, Hyderabad and Nawabshah was calculated from (1). We indicate that other methods are also available in the literature to evaluate these constants such as Rietveld [11], [12], Glover and McCulloch [13] and Gopinathan [14].



(a)



(b)

Fig. 1 (a) Map of Sindh, Pakistan (b) Annual average mean daily solar radiation in Pakistan

A. Extra-Terrestrial Radiation on Horizontal Surface (H_0)

The solar radiation outside the atmosphere incident on the horizontal surface is given by the following expression [15]

$$H_0 = (24 * 3600)/\pi \; Isc\,([1 + 0.033\,cos(360n/365])\,[cos\Phi\,cos\delta\;\,sin\,Ws + 2\pi\;\,Ws/\,360\,sin\,\Phi\;\,sin\delta] \quad (3)$$

H_0 is the extraterrestrial insulation on horizontal surface where Isc is the solar constant, Φ the latitude, δ the solar declination, Ws is the sunset hour angle, N is the day length (N= 2/15 Ws)

$$\delta = 23.45\,sin\,\{\,360\,x\,248\; + n/365\} \quad (4)$$

$$cosWs = -tan\theta\;tan\,\delta \quad (5)$$

B. Prediction of Diffuse Solar Radiation (H_d)

Diffuse solar radiation H_d can be estimated by an empirical formula that correlates the diffuse solar radiation component $H_d$to and daily total radiation H. The widely used correlation equation, developed by Page [7], and Liu and Jordan [8], respectively is:

$$H_d/H = 1.00 - 1.13\,K_T \quad (6)$$

$$H_d/H = 1.390 - 4.027\,K_T + 5.53\,(K_T)^2 - 3.108\,(K_T)^3 \quad (7)$$

where H_d is the monthly mean of the daily diffuse solar radiation and H is the daily total solar radiation and K_T is the clearness index [10], [14].

$$K_T = H/H_0 \quad (8)$$

III. Wind Speed Patterns of Sindh

The heating of air in India's great deserts namely, Rajasthan and Thar, brings about winds in the Sindh province. Hot air rises upwards and is replaced by colder air coming in from the Arabian Sea. The Lower region of Sindh has more wind than the upper region. Wind speed data shows that a high wind velocity belt exists between Karachi and Keti Bander to Mithi and Karachi to Hyderabad and beyond to the desert (Fig. 2). The results show that the coastal areas of Sindh have a higher wind energy potential than northern Sindh.

A. Wind Power

Wind power (WP) is represented by:

$$WP\;(Max.Available\;Power) = 1/2\;pAv^3 \quad (9)$$

where p is the density of the air, A is the rotor sweep area, *v* is the average wind speed and WP is wattage

$$WP\;(Max.Extractable\;Power) = 1/2\;pC_pAV^3 \quad (10)$$

C_p is the power coefficient of the machine C_p=16/27

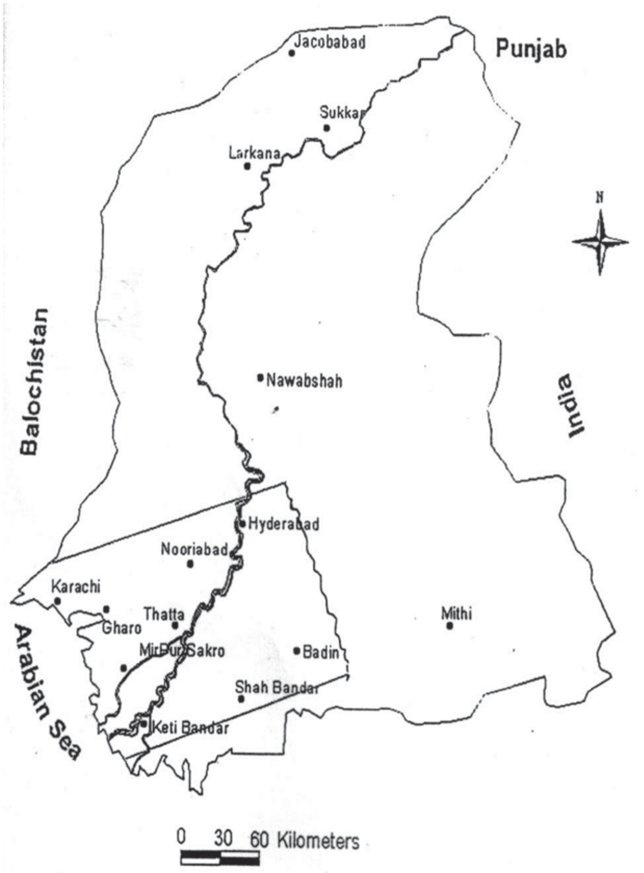


Fig. 2 Wind Energy Potential Zones in Sindh Province

B. Weibull Parameters, k and c

The parameter 'k' and 'c' can be evaluated by using the monthly mean wind speed *v* and the standard deviation ∂ of the monthly mean wind speed by solving the following equation [16]:

$$k = (\partial/v)^{-1.086} \quad (11)$$

$$c = v/r\,(1 + 1/k) \quad (12)$$

where 'r' is a gamma function. The value of the gamma function can be seen from the standard gamma function table. Standard deviation can be calculated with:

$$\partial = \sqrt{\sum (X_i - X)^2}\;/\text{n} \quad (13)$$

C. Wind Power Density

The wind power density (WPD) is the amount of wind power available per unit area perpendicular to the wind flow measured in watt/m^2. In practice wind power density is used to estimate the potential of the electrical output of the wind farm.

$$WPD = 1/2\;pv^3 \quad (14)$$

TABLE I
GEOGRAPHICAL LOCATIONS, SUNSHINE RECORD AND WIND RECORD FOR SOME OF THE CITIES IN SINDH

Cities	Latitude (N) Deg, min	Longitude (E) Deg, min	Max. Temp (C)	Min. Temp (C)	Sunshine hour Record (years)	Wind speed Record (years)
Karachi	24,54	66,14	38	13	10	5
Hyderabad	25,35	68,20	42	25	5	5
Nawabshah	26,25	68,20	43	25	5	5
Hawks bay	24,54	66,14	35	12	-	5
KetiBander	24,14	67,44	36	13	-	5
ShahBander	24,63	67,36	36	15	-	5

IV. Results and Discussion

The geographical locations of some of the cities of interest are given in Table I. The information on monthly mean sunshine hours and day length for the cities of Sindh indicate approximately 09 to 10 hours of sunshine for Nawabshah city. While for Karachi and Hyderabad in the months of July and August, the presence of cloud limits the cities to approximately 03 to 05 hours of sunshine. Moreover, all cities in the Sindh region experience 10 to 13 hour-long days in winter and summer. The Angstrom coefficient 'a' and 'b' are evaluated using relationship given by Sangeeta and Tewari. The monthly average daily Global solar radiation H, the extraterrestrial solar radiation H_0 and the Diffuse solar radiation H_d for all the cities were evaluated and shown in Figs. 3-5. From the figures shown, it appears that for Karachi and Hyderabad in the months of July and August there is a sharp drop in global solar radiation because these are the monsoon months for these cities.

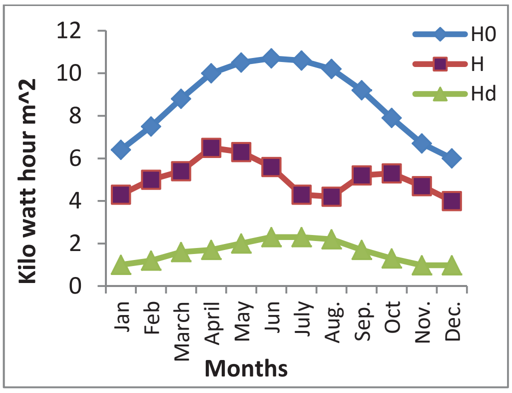


Fig. 3 Monthly variation of Extraterrestrial, Global and Diffuse solar radiation for Karachi, Sindh

The K_T values (clearness index) remains below 0.7 for the three cities under observation. In the monsoon months where the clouds are in abundance, the K_T values fall between 0.4 and 0.5 for Karachi and Hyderabad, as shown in Figs. 6 and 7. For these two cities during the monsoon months, diffuse radiation is high, as would be expected. However, due to the geographical location of Nawabshah and the lack of clouds during the monsoon months, Nawabshah sees no drastic change in its K_T values (Fig. 8). The K_T values (clearness index) remains between 0.62 and 0.63.

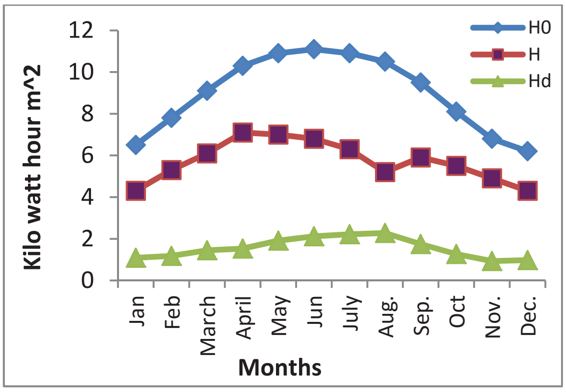


Fig. 4 Monthly variation of Extraterrestrial, Global and Diffuse solar radiation for Hyderabad, Sindh

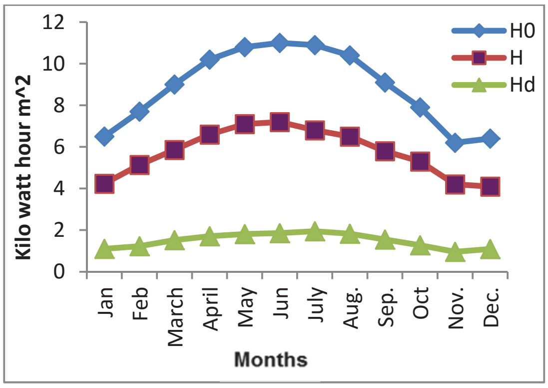


Fig. 5 Monthly variation of Extraterrestrial, Global and Diffuse solar radiation for Nawabshah, Sindh

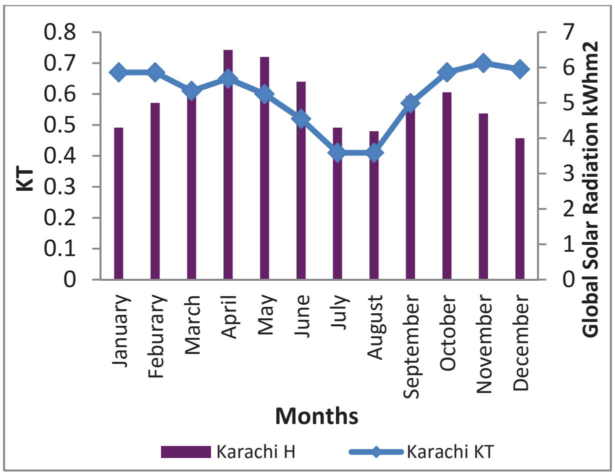


Fig. 6 Global Solar Radiation and Clearness Index for Karachi

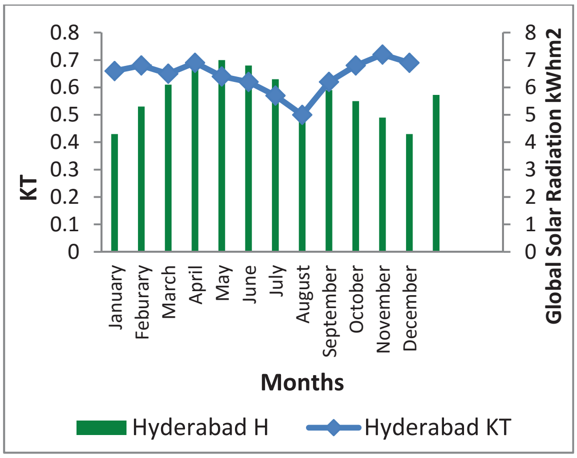


Fig. 7 Global Solar Radiation and Clearness Index for Hyderabad

For Nawabshah (Fig. 8), the availability of global solar radiation H is very encouraging from the utilization point of view. The transmission of diffuse radiation from extraterrestrial radiation is only 17%, which is due to the absorption and scattering of solar radiation.

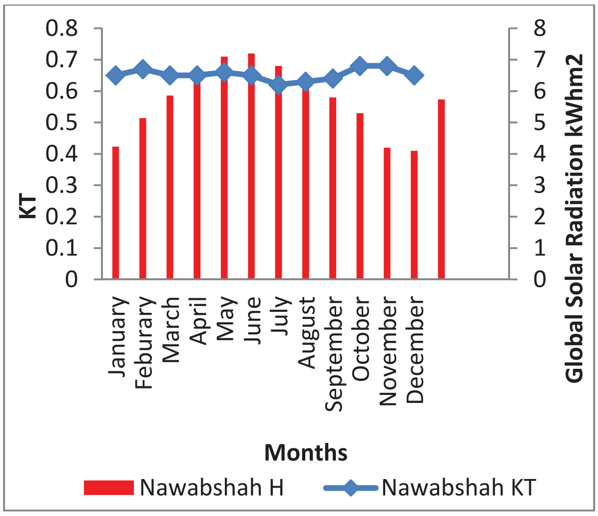


Fig. 8 Global Solar Radiation and Clearness Index for Nawabshah

A. Sky Conditions for Southern Cities of Sindh

TABLE II
THE SKY CONDITIONS OBSERVED FOR SOUTHERN CITIES OF SINDH (% DIRECT SOLAR RADIATION)

Months	Karachi	Hyderabad	Nawabshah
Jan-Apr	above 64	above 67	above 66
May-Jun	above 56	above 60	above 65
Jul-Aug	above 40	above 50	above 62
Sept-Dec	above 65	above 65	above 66

Table II provides the percentage of global solar radiation for the southern cities of Sindh. In the monsoon months (July and August), global solar radiation for Karachi and Hyderabad is 50% and below. However, the percentage of H in Nawabshah is higher than 50%. All cities observe maximum global solar radiation, H, values per year from the months of September to December, and January to June.

B. Diffuse and Direct Solar Radiation in Sindh

In July and August, diffuse radiation is higher in Karachi and Hyderabad, varying in between 35% to 53%, whereas for Nawabshah, it ranges between 26% and 28%, as shown in Tables III-V. It appears that solar panels can be utilized efficiently for Nawabshah all year round. But for these months, the efficiency of solar panels in Karachi and Hyderabad may reduce by a further 50%, approximately (Fig. 9).

The direct solar radiation available in these cities can be used efficiently. The cities of Karachi, Hyderabad and Hawksbay observe the most direct solar radiation during the year, except during the monsoon months of July and August. However, Nawabshah is expected to see even higher direct solar radiation (as compared to Karachi and Hyderabad) all year round, including the months of July and August.

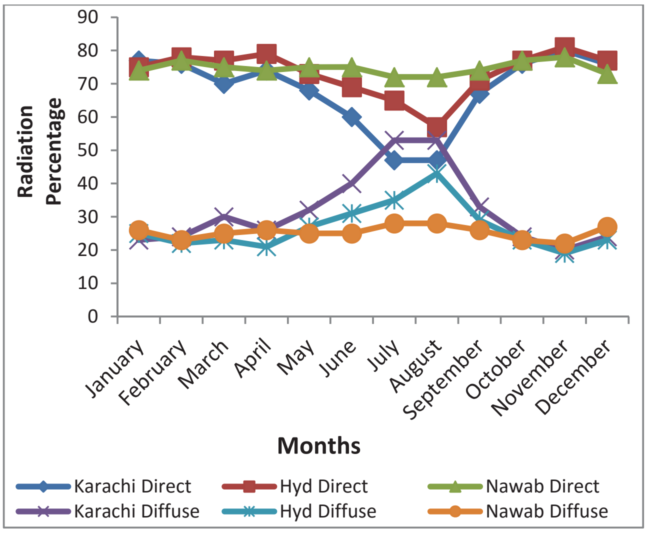


Fig. 9 The pattern of variation of direct and diffuse solar radiation for three cities of Sindh

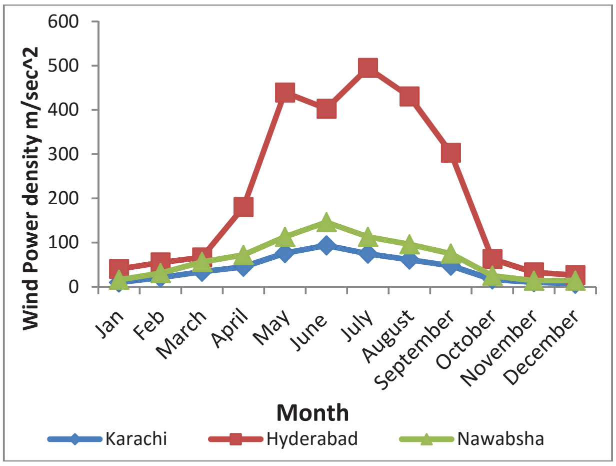


Fig. 10 Seasonal variation of wind power density at 10m height

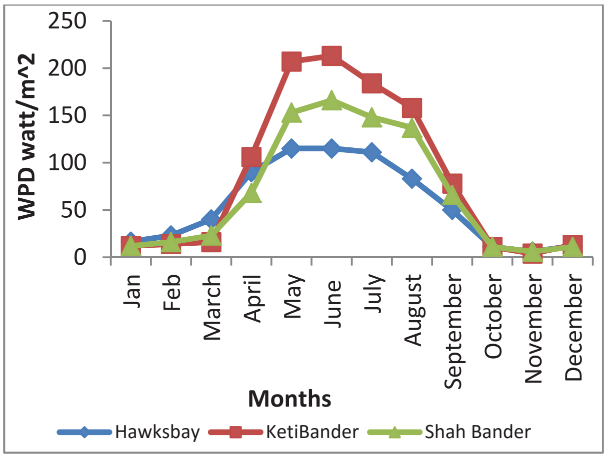


Fig. 11 Seasonal variation of wind power density at an altitude of 10m

C. Comparison with NASA SSE Model (22-Year Average) [15]

The estimated values for Global solar radiation, H_{est}, found from eh method of Sangeeta and Tewari, and values obtained from NASA SSE model (22 year average), H_{NASA}, are presented in Table VI. It is found that H_{NASA} is very much higher than H_{est}. However, H_{est} is generally higher than H_{NASA} throughout the year.

The estimated values for Diffuse Solar Radiation obtained from the average of the Lui-Jordan and Page methods, H_{dest} and the NASA SSE model H_{dNASA}, are presented in Table VII. The H_{dest} follows a similar pattern as H_{dNASA} throughout the year. For both $H_{dest}$and H_{dNASA}, diffuse radiation is seen to be the most in the summer months, especially July and August (Monsoon months). Hyderabad and Nawabshah, observe higher values of H_{dNASA} than H_{dest} almost all year round, except in Karachi, where $H_{dest}$is higher than H_{dNASA}.

TABLE III
THE EXTRATERRESTRIAL, GLOBAL AND DIFFUSE SOLAR RADIATION FOR THREE CITIES OF SINDH (KWH/M^2)

Month	Karachi			Hyderabad			Nawabshah		
	H_0	H	H_d	H_0	H	H_d	H_0	H	H_d
January	6.4	4.3	1	6.5	4.3	1.09	6.5	4.23	1.1
February	7.5	5	1.21	7.8	5.3	1.18	7.7	5.14	1.23
March	8.8	5.4	1.62	9.4	6.1	1.45	9	5.86	1.52
April	10	6.5	1.72	10.3	7.13	1.53	10.2	6.6	1.71
May	10.5	6.3	2.03	10.9	7.03	1.91	10.8	7.1	1.81
June	10.7	5.6	2.27	11.1	6.83	2.12	11	7.18	1.86
July	10.6	4.3	2.3	10.9	6.26	2.22	10.9	6.75	1.95
August	10.2	4.16	2.23	10.5	5.2	2.28	10.4	6.5	1.83
September	9.2	5.2	1.72	9.5	5.9	1.75	9.1	5.8	1.55
October	7.9	5.3	1.28	8.1	5.5	1.27	7.9	5.34	1.27
November	6.7	4.7	0.98	6.8	4.9	0.93	6.2	4.2	0.96
December	6	4.06	0.98	6.2	4.25	0.98	6.4	4.13	1.09

D. Wind Potential for the Lower Sindh Region

As Karachi and Hyderabad show lower solar potential in the monsoon months, the authors analyze the wind potential in the south of Sindh at a height of 10 m. Wind turbines can be placed to compensate for the direct solar radiation deficiency. The coast of Karachi has an average annual wind speed of 4 m/s to 9 m/s at 10 m heights with a theoretical capacity factor exceeding 15% [16]. A 20 m diameter wind turbine at a height of 30 m is therefore able to generate 2 MW of power. The coast of Karachi can be used for grid-connected applications with small-scale wind farms developed throughout. The analysis of data shows that the seasonal patterns of wind speed and wind power density matches the electricity load pattern of the coastal city of Sindh (Figs. 10 and 11).

The wind power density value results of the southern region are encouraging. A feasibility study using N-60 machine having rated output 1,300 KW and cut in speed 4 m/s has been carried out. During April to September, when the average wind speed is 9 m/s with 20% losses, the maximum output from a 17 acre wind farm (20 machines per acre) will produce 250 MW from the coastal areas of Karachi (especially Hawksbay, Ketibander, and Shahbander) [16].

With some financial investment, plus some yearly maintenance costs, solar panels and wind turbines can be constructed to provide power to Sindh villages in particular and to the province of Sindh in general. The combination of solar and wind is feasible in the southern parts of Sindh, Pakistan.

TABLE IV
THE CLEARNESS INDEX FOR THREE CITIES OF SINDH

Month	K_T Karachi	K_T Hyderabad	K_T Nawabshah
January	0.67	0.66	0.65
February	0.67	0.68	0.67
March	0.61	0.65	0.65
April	0.65	0.69	0.65
May	0.60	0.64	0.66
June	0.52	0.62	0.65
July	0.41	0.57	0.62
August	0.41	0.50	0.63
September	0.57	0.62	0.64
October	0.67	0.68	0.68
November	0.70	0.72	0.68
December	0.68	0.69	0.65

V. CONCLUSION

The work carried out in this paper indicates the potential of solar and wind for the use as a reliable energy source for the southern cities of Sindh. The estimated result of the total and diffuse solar radiation indicates that solar energy can be efficiently used to compensate the energy short fall in these regions of Sindh. Since limited research work on such topics has been reported prior to this work, this paper is expected to be of help to determine the solar potential in these cities for experts of energy and strategies.

Methods suggested by Sangeeta and Tiwari to find regression constants applied with the Angstrom model are stated in this paper. The Global and diffuse solar radiation calculated by the Sangeeta/Tewari method are compared with the 22-year average measured values obtained from NASA. The estimated values are in good agreement with NASAs 22-year average values. The diffuse solar radiation is calculated using the method proposed by Page and Liu and Jordon. In all these cities, the highest monthly diffuse radiation was observed in the monsoon months.

Ultimately, the wind speeds observed in these areas remains higher during the monsoon months. This compensates for the higher diffuse solar radiation in these months (Monsoon months). Hence, wind energy is also an additional prospective in these cities. A combination of both solar and wind has tremendous potential for use as a ‘clean, green’ alternate power resource for Sindh province.

TABLE V
THE ESTIMATED AND NASA SSE MODEL DATA (22 YEAR AVERAGE) FOR GLOBAL SOLAR RADIATION (KWH/M^2)

Months	KARACHI		HYDERABAD		NAWABSHAH	
	H_{est}	H_{NASA}	H_{est}	H_{NASA}	H_{est}	H_{NASA}
Jan	4.3	4.76	4.3	3.7	4.23	3.99
Feb	5	5.67	5.3	4.42	5.14	4.71
March	5.4	6.68	6.1	5.41	5.86	5.41
April	6.5	7.31	7.13	6.41	6.6	6.09
May	6.3	7.23	7.03	6.88	7.1	6.42
Jun	5.6	6.3	6.83	6.98	7.18	6.41
July	4.3	6.11	6.26	6.2	6.75	5.77
Aug	4.16	6.32	5.2	5.95	6.5	5.6
Sept	5.2	5.91	5.9	5.62	5.8	5.56
Oct	5.3	5.11	5.5	4.54	5.34	5
Nov	4.7	4.53	4.9	3.7	4.2	4.21
Dec	4.06	6.13	4.25	3.42	4.13	3.75

TABLE VI
THE ESTIMATED AND NASA SSE MODEL DATA (22 YEAR AVERAGE) FOR DIFFUSE SOLAR RADIATION (KWH/M^2)

Months	KARACHI		HYDERABAD		NAWABSHAH	
	H_{dest}	H_{dNASA}	H_{dest}	H_{dNASA}	H_{dest}	H_{dNASA}
Jan	1	0.81	1.09	1.17	1.1	1.02
Feb	1.21	0.97	1.18	1.42	1.23	1.27
March	1.62	1.2	1.45	1.7	1.52	1.64
April	1.72	1.53	1.53	1.89	1.71	1.98
May	2.03	1.77	1.91	2.06	1.81	2.21
Jun	2.27	2.04	2.12	2.13	1.86	2.32
July	2.3	2.27	2.22	2.3	1.95	2.39
Aug	2.23	2.09	2.28	2.12	1.83	2.19
Sept	1.72	1.57	1.75	1.79	1.55	1.78
Oct	1.28	1.06	1.27	1.55	1.27	1.35
Nov	9.98	0.78	0.93	1.29	0.96	1.06
Dec	0.98	0.74	0.98	1.11	1.09	0.95

TABLE VII
PERCENTAGE VARIATION OF DIRECT AND DIFFUSE SOLAR RADIATION FOR KARACHI, HYDERABAD AND NAWABSHAH

Month	Karachi Direct	Karachi Diffuse	Hyderabad Direct	Hyderabad Diffuse	Nawabshah Direct	Nawabshah Diffuse
January	77	23	75	25	74	26
February	76	24	78	22	77	23
March	70	30	77	23	75	25
April	74	26	79	21	74	26
May	68	32	73	27	75	25
June	60	40	69	31	75	25
July	47	53	65	35	72	28
August	47	53	57	43	72	28
September	67	33	71	29	74	26
October	76	24	77	23	77	23
November	80	20	81	19	78	22
December	76	24	77	23	73	27

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