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Solar Radiation Studies for Dubai and Sharjah, UAE

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***Abstract*—**Global Solar Radiation (H) for Dubai and Sharjah, Latitude 25.25°N, Longitude 55°E and 25.29°N, Longitude 55°E respectively have been studied using sunshine hour data (n) of the areas using various methods. These calculated global solar radiation values are then compared to the measured values presented by NASA. Furthermore, the extraterrestrial (H_0), diffuse (H_d) and beam radiation (H_b) are also calculated. The diffuse radiation is calculated using methods proposed by Page and Liu and Jordan (L-J). Diffuse Radiation from the Page method is higher than the L-J method. Moreover, the clearness index (K_T) signifies a clear sky almost all year round. Rainy days are hardly a few in a year and limited in the months December to March. The temperature remains between 25°C in winter to 44°C in summer and is desirable for thermal applications of solar energy. From the estimated results, it appears that solar radiation can be utilized very efficiently throughout the year for photovoltaic and thermal applications.

***Keywords*—**Dubai, Sharjah, Global Solar Radiation, Diffuse Radiation.

I. Introduction

DUBAI (Latitude 25.25° N, Longitude 55° E) is situated on the southwest of Sharjah (Latitude 25.29° N, Longitude 55° E) within the Arabian Desert and shares boundaries with Abu Dhabi in the south as shown in Fig.1 [1].

Plentiful amount of solar radiation is observed between the latitudes of 40°N and 40°S and is referred to as the Solar-Belt of the earth. Aksakal and Rehman have reported daylight of 4449 h/year at latitude of 25°N with 70% being sunshine [2]. The UAE is abundant in fossil fuels and is the seventh largest oil reserve in the world. However, it is vital to introduce a ‘clean and green’ agenda in the energy market. The solution to this problem rests in employing the alternate energy resources which include solar, wind and biomass. The abundance of solar radiation in this area makes it feasible for solar energy utilization.

To evaluate the solar energy potential of an area, it is essential to calculate the local solar radiation. One way of a good approximation is through continuous, long-term measurements of data at the site of interest. These values can then be compared to the calculated solar radiation using methods proposed in literature [3]-[9].

A number of empirical formulas have been developed to estimate the global and diffuse solar radiation using a range of parameters. These parameters include the sunshine hours [10]-[12], the relative humidity and sunshine hours [13], the declination angle and the latitude [14], the number of rainy days, sunshine hours, latitude and locations [15], the sunshine duration, relative humidity, maximum temperature, latitude, altitude and location [16] and the total precipitation, water, turbidity and surface albedo [17].

Furthermore, many other workers have reported the estimation of global and diffuse solar radiation employing various climatological parameters [18]-[24]. In the present work, solar radiation estimation (global and diffuse) has been carried out for Dubai and Sharjah using sunshine hour data. The number of methods used to find global solar radiation (H) is namely Sangeeta and Tewari [3], Gopinathan [7], Rietveld [5], [6] and Glover and McColloch [4].

The work carried out in this paper: (1) Discusses the results obtained for Global solar radiation by different methods and compares them to the 22- year average data from NASA [25]; (2) Evaluates the diffuse and the beam radiation from the method proposed by Sangeeta and Tiwari [3]; and finally, considers the energy potential in this part of the Gulf region for solar applications.

Fig. 1 The map of UAE showing Dubai and Sharjah at the top right hand side [1]

II. Methodology

A. Extra-Terrestrial Solar Radiation (H_0)

The value of H_0, extra terrestrial solar radiation, is determined by of Duffie and Beckman [26].

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

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where I_{sc} is the solar constant, φ is the latitude, δ is the solar declination, W_s is the sunset hour angles where

$$\delta = 23.45 \sin \{ 360 \, x \, 248 + n/365 \} \quad (2)$$
$$\cos W s = -\tan\theta \tan \delta \quad (3)$$

B. Prediction of Global Solar Radiation (H)

Amongst the above mentioned empirical models, the most popular is the regression equation of the Angstrom type [10].

$$H/H_O = a + b\,(n/N) \quad (4)$$

where *H* is the monthly average daily global solar radiation falling on a horizontal surface at a particular location. H_0 is the monthly mean daily extraterrestrial radiation on a horizontal surface in the absence of the atmosphere, *n* is the monthly mean daily number of hours of observed sunshine, *N* is the monthly mean value of the day length at a particular location, '*a*' and '*b*' are climatologically determined regression constants, *n/N* is often called the percentage of possible sunshine hour.

Regression constants *a* and *b* have been obtained from the relationship given as Tiwari and Sangeeta in 1977 [3] and also confirmed by Frere et al. method [27].

$$a = -0.110 + 0.235 \cos\Phi + 0.323\,(n/N) \quad (5a)$$
$$b = 1.449 - 0.553 \cos\Phi - 0.694\,(n/N) \quad (5b)$$

Gopinathan [7] recommended the regression coefficient 'a' and 'b' in terms of the latitude, elevation and percentage of possible sunshine hour for any location around the world. Dubai is 0.016 km above sea level whereas Sharjah is 0.762 km above sea level [28], [29]. The correlations are given below.

$$5 < \Phi < 54$$
$$a = -0.309 + 0.539 \cos\Phi - 0.0693 E_0 + 0.29\,(n/N) \quad (6a)$$
$$b = 1.527 - 1.027 \cos\Phi + 0.926 E_0 - 0.359\,(n/N) \quad (6b)$$

After examining several publications, Rietveld [5], [6] suggested the following regression coefficients.

$$0 < \Phi < 69$$
$$a = +0.1 + 0.24\,(n/N) \quad (7a)$$
$$b = 0.38 + 0.08\,(N/n) \quad (7b)$$
$$H/H_0 = 0.18 + 0.62 (n/N)$$

Glover and McColloch in Iqbal [4] incorporated the latitude of the area ɸ (degrees) effect and presented the following correlation.

$$\Phi < 60$$
$$a = 0.26 \cos\Phi \quad (8a)$$
$$b = 0.52 \quad (8b)$$
$$H/H_0 = 0.29 \cos\Phi + 0.52 (n/N)$$

C. Prediction of Diffuse Solar Radiation (H_d)

The diffuse solar radiation H_d can be estimated by an empirical formula which correlates the diffuse solar radiation component H_d to the daily total radiation H. The correlation equation which is widely used is developed by Page [30]

$$H_d/H = 1.00 - 1.13\, K_T \quad (9)$$

H_d is the monthly mean of the daily diffuse solar radiation and $K_T = H/H_0$ is the clearness index. Another commonly used correlation is due to Liu and Jordan (1960) [14] and developed by Klein [31] and is of the form

$$H_d/H = 1.390 - 4.027\, K_T + 5.53\,(K_T)^2 - 3.108\,(K_T)^3 \quad (10)$$

III. Results and Discussions

Table I presents the input parameters for the estimation of the monthly average daily solar radiation. The sunshine duration observed is between 75-85%. Taking account of this, the regression constants 'a' and 'b' have been calculated for each month using (5a) to (8b). Using method proposed by Sangeeta and Tiwari [3], 'a' and 'b' are found to be 0.36 and 0.38 for Dubai and 0.35 and 0.41 for Sharjah. The monthly average daily Global solar radiation on the horizontal surface, *H*, has been calculated using (5a) to Eq. (8b) for a number of methods and shown in Fig. 2(a) and 2(b) for Dubai and Sharjah respectively (Table II(a) and II(b)). These values of Global solar radiation have been compared with NASA 22-year average measured values [25]. The calculated values using above mentioned equations appear higher than the NASA values. The values obtained from Rietveld [5], [6] are highest from April to November as compared to others. For Sangeeta and Tiwari [3], the values of Global solar radiation show a higher trend from December to March.

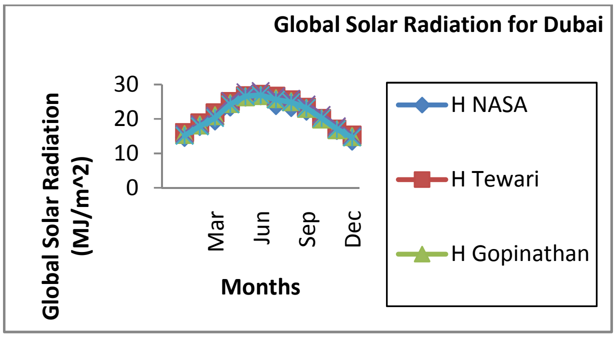

Fig. 2 (a). Values of the average monthly global solar radiation *H* (MJ/m^2) calculated from a number of methods for Dubai, U.A.E

The value obtained from the method proposed by Gopinathan [7] is expected to yield the best results because it involves the use of 3- variables instead of 2- variables in Sangeeta Tiwari [3].

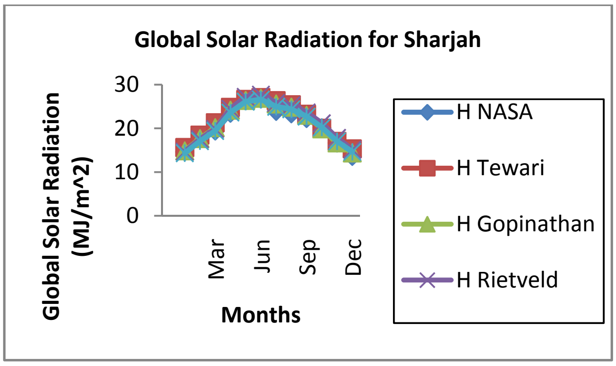

Fig. 2 (b). Values of the average monthly global solar radiation H (MJ/m^2) calculated from a number of methods for Sharjah, U.A.E

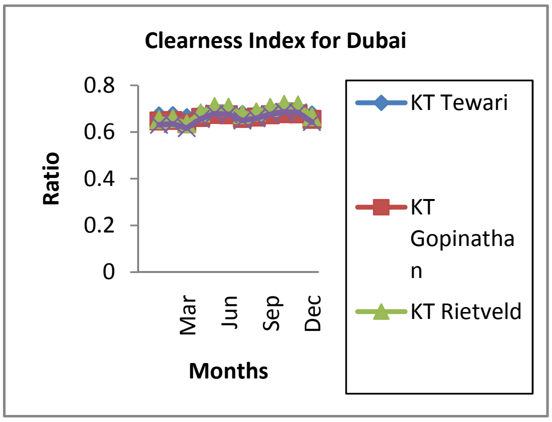

Fig. 3 (a). Values of Clearness Index, K_T, calculated from a number of methods for Dubai, U.A.E

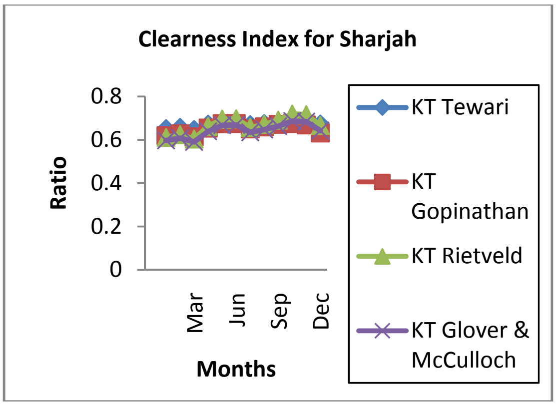

Fig. 3 (b). Values of Clearness Index, K_T, calculated from a number of methods for Sharjah, U.A.E

Table III gives the value of Clearness Index calculated by different methods for Dubai and Sharjah and this is shown in Fig. 3(a) and 3(b). It appears that the month of March for both the places are rainy months when the sky is cloudy. April to June is hot and shiny. The month of July appears as monsoon month without rain (Fig. 4(a) and 4(b)).

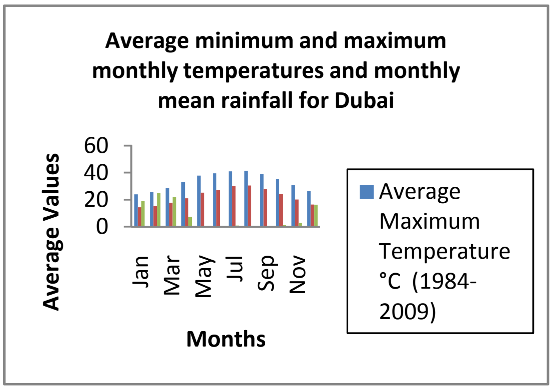

Fig. 4 (a). The amount of precipitation per month along with the average monthly maximum and minimum temperatures for Dubai, U.A.E [28]

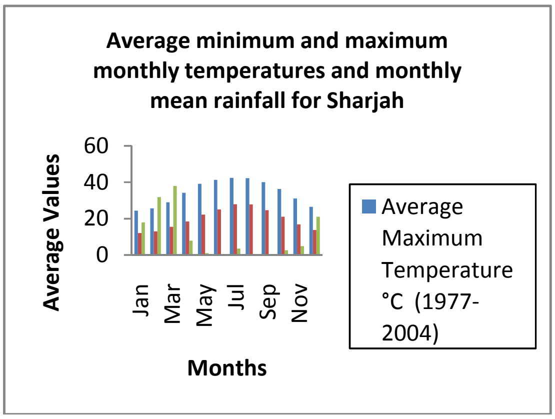

Fig. 4 (b). The amount of precipitation per month along with the average monthly maximum and minimum temperatures for Sharjah, U.A.E [29]

Table IV(a) and IV(b) give the diffuse solar radiation for Dubai and Sharjah using Page [30] and Liu and Jordon [14] methods. From the estimated results, it is found that the contribution of diffuse solar radiation of Dubai and Sharjah all around the year is between 20 to 25%. Liu and Jordon predict lower value of diffuse radiation than the Page method.

The availability of direct radiation is very encouraging from consumption point of view. From our observation of Clearness Index and the ratio of diffuse to global radiation, we conclude that the presence of cloud is very rare or only a few days in a year. This seems favourable for solar energy utilization in Dubai and Sharjah. The diffuse radiation is extremely low as compared to the global and beam radiation falling on the horizontal surface (Fig. 5(a) and 5(b)).

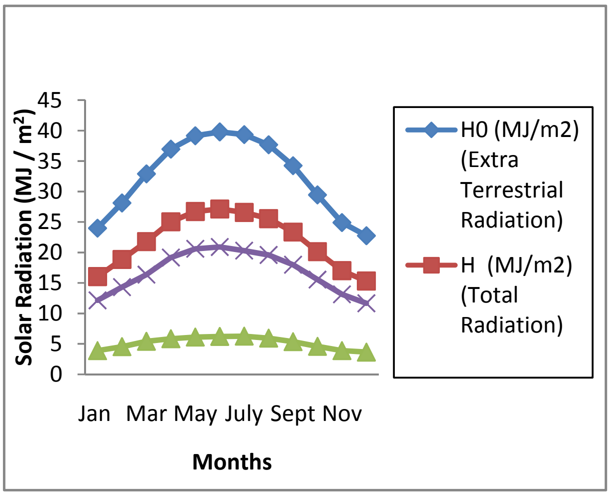

Fig. 5 (a). Monthly variation of extraterrestrial radiation (H_0), total radiation (H), diffuse radiation (D) and beam radiation (H_b) for Dubai.

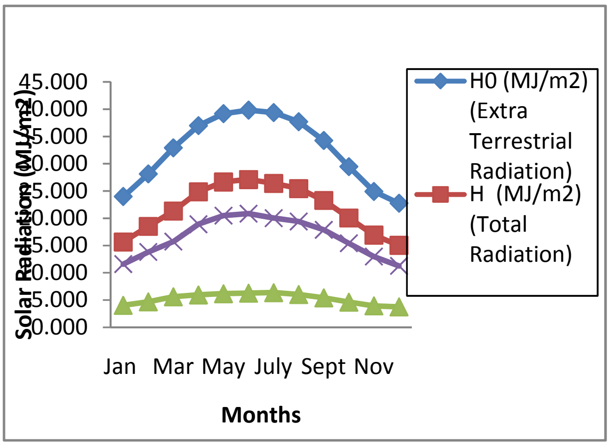

Fig. 5 (b). Monthly variation of extraterrestrial radiation (H_0), total radiation (H), diffuse radiation (D) and beam radiation (H_b) for Sharjah

A. Sky Conditions: Dubai and Sharjah

The transparency of atmosphere is indicated by the fraction of extraterrestrial solar radiation which reaches the earth surface as global radiation. It is a measure of degree of the clearness of the sky, also called the Clearness Index and represented by K_T

$$K_T = H/H_0 \tag{11}$$

H is the total or global solar radiation and H_0 is the extraterrestrial solar radiation. From the estimated value of H in Dubai and Sharjah, K_T can be calculated.

Fig. 3(a) and 3(b) represents the transmission coming through the atmosphere K_T by a number of methods. The Clearness Index remains between 60 to 70% throughout the year in Dubai and Sharjah. It is very encouraging to note that the sky over Dubai and Sharjah remains fairly clear during the whole summer and winter months. However, with the exception of December to March where the probability of rain is high, although merely by approximately 6% (Fig. 4(a) and 4(b)). The Global solar radiation is expected to be high (as in Fig. 2(a) and 2(b)) when both the Clearness Index (Fig. 3(a) and 3(b)) and the temperature are high (Fig. 4(a) and 4(b)), as would be expected in the summer months in both Dubai and Sharjah.

Table V shows the statistical distribution of global solar radiation H which indicates that the availability of global solar radiation is approximately 65% during the winter months in Sharjah and above 67% during the winter and summer months in Dubai.

$$H = H_d + D \tag{12}$$

where H_b is the beam radiation and D is the average diffuse radiation.

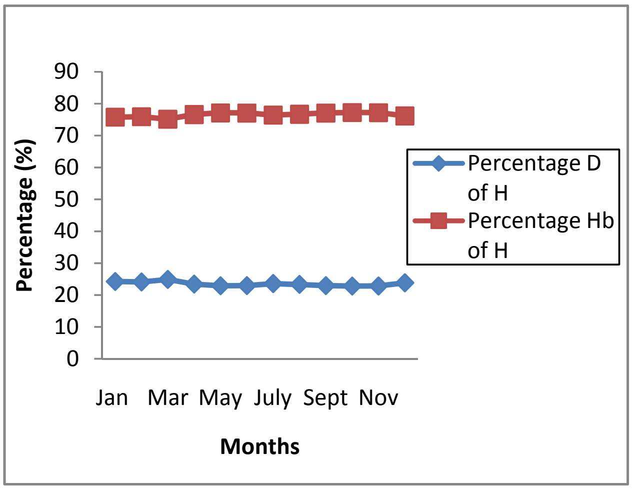

Fig. 6 (a) Percentage variation of Direct and Diffuse radiation at Dubai

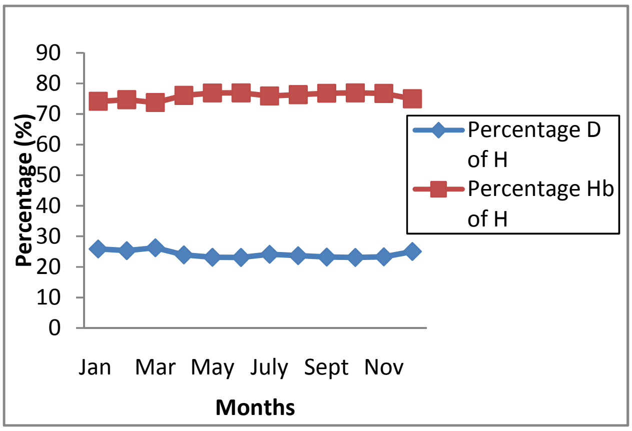

Fig. 6 (b) Percentage variation of Direct and Diffuse variation at Sharjah

B. Variation of Direct and Diffuse Solar Radiation

Large variations in the intensities of direct and diffuse radiation appear. Fig. 6(a) and 6(b) exhibits the trend of the percentage variation of direct and diffuse solar radiation of Dubai and Sharjah. Direct Radiation is appreciable in the months April to November in both the cities. The percentage of diffuse radiation contributing to global radiation is more in winter months (Dec-March) as compared to the summer months although not by much and tends to keep in the range of 20-25%. Finally, the diffuse radiation is generally seen to be higher in Sharjah than in Dubai, all around the year.

The abundant presence of direct radiation especially from April till November makes Dubai and Sharjah ideal for the use of solar energy as an alternate energy resource. Solar concentrators, solar cookers, solar furnaces etc. can be installed at these locations to utilize this free energy source. The Angstrom model for the determination of global solar radiation and Liu and Jordan model for the estimation of diffuse solar radiation exhibits the validity of estimation for the location under study.

TABLE I (A)
INPUT PARAMETERS FOR ESTIMATION OF MONTHLY AVERAGE GLOBAL SOLAR RADIATION FOR DUBAI

Months	n	N	n/N
	Mean Sunshine Hours (1974-2009) [28]	**Monthly Average Day Length**	**Possible Sunshine Hours**
Jan	8.10	10.62	0.76
Feb	8.60	11.17	0.77
Mar	8.70	11.85	0.73
Apr	10.20	12.60	0.81
May	11.30	13.23	0.85
Jun	11.50	13.55	0.85
July	10.70	13.41	0.80
Aug	10.50	12.87	0.82
Sept	10.30	12.14	0.85
Oct	9.90	11.39	0.87
Nov	9.30	10.76	0.86
Dec	8.20	10.46	0.78

TABLE I (B)
INPUT PARAMETERS FOR ESTIMATION OF MONTHLY AVERAGE GLOBAL SOLAR RADIATION FOR SHARJAH

Months	n	N	n/N
	Mean Sunshine Hours (1977-2004) [29]	**Monthly Average Day Length**	**Possible Sunshine Hours**
Jan	7.40	10.61	0.70
Feb	8.00	11.17	0.72
Mar	8.10	11.85	0.68
Apr	9.80	12.60	0.78
May	11.00	13.23	0.83
Jun	11.30	13.55	0.83
July	10.30	13.41	0.77
Aug	10.20	12.87	0.79
Sept	10.00	12.14	0.82
Oct	9.50	11.39	0.83
Nov	8.80	10.76	0.82
Dec	7.60	10.46	0.73

TABLE II (A)
VALUES OF THE AVERAGE MONTHLY GLOBAL SOLAR RADIATION H (MJ/M^2) CALCULATED FROM A NUMBER OF METHODS FOR DUBAI, U.A.E

Months	**H NASA [25]**	**H Tiwari [3]**	**H Gopinathan [7]**	**H Rietveld [5], [6]**	**H Glover & McCulloch [4]**
Jan	14.62	16.05	15.53	15.67	15.16
Feb	17.82	18.86	18.27	18.50	17.88
Mar	19.40	21.79	20.96	20.90	20.30
Apr	23.47	25.04	24.49	25.21	24.26
May	26.35	26.73	26.45	27.78	26.60
Jun	26.75	27.15	26.82	28.11	26.93
Jul	23.90	26.59	25.92	26.56	25.59
Aug	23.33	25.56	25.03	25.85	24.85
Sep	22.25	23.36	23.08	24.18	23.17
Oct	20.16	20.14	20.01	21.18	20.24
Nov	16.67	17.03	16.89	17.84	17.06
Dec	13.57	15.32	14.89	15.16	14.63

TABLE II (B)
VALUES OF THE AVERAGE MONTHLY GLOBAL SOLAR RADIATION H (MJ/M^2) CALCULATED FROM A NUMBER OF METHODS FOR SHARJAH, U.A.E

Months	**H NASA [25]**	**H Tiwari [3]**	**H Gopinathan [7]**	**H Rietveld [5], [6]**	**H Glover & McCulloch [4]**
Jan	14.62	15.63	14.85	14.67	14.33
Feb	17.82	18.49	17.66	17.55	17.09
Mar	19.40	21.30	20.17	19.86	19.43
Apr	23.47	24.84	24.18	24.48	23.64
May	26.35	26.64	26.42	27.23	26.14
Jun	26.75	27.09	26.89	27.74	26.62
Jul	23.90	26.37	25.59	25.83	24.98
Aug	23.33	25.42	24.87	25.30	24.39
Sep	22.25	23.26	23.00	23.65	22.72
Oct	20.16	20.04	19.89	21.18	20.24
Nov	16.67	17.03	16.67	17.84	17.06
Dec	13.57	15.32	14.39	15.16	14.63

TABLE III (A)
MEASURE OF THE CLEARNESS INDEX, K_T, BY VARIOUS METHODS FOR DUBAI

Months	K_T Tiwari	K_T Gopinathan	K_T Rietveld	K_T Glover & McCulloch
Jan	0.67	0.65	0.65	0.63
Feb	0.67	0.65	0.66	0.64
Mar	0.66	0.64	0.64	0.62
Apr	0.68	0.66	0.68	0.66
May	0.68	0.68	0.71	0.68
Jun	0.68	0.67	0.71	0.68
Jul	0.68	0.66	0.67	0.65
Aug	0.68	0.66	0.69	0.66
Sep	0.68	0.67	0.71	0.68
Oct	0.68	0.68	0.72	0.69
Nov	0.68	0.68	0.72	0.68
Dec	0.67	0.65	0.67	0.64

TABLE III (B)
MEASURE OF THE CLEARNESS INDEX, K_T, BY VARIOUS METHODS FOR SHARJAH

Months	K_T Tiwari	K_T Gopinathan	K_T Rietveld	K_T Glover & McCulloch
Jan	0.65	0.62	0.61	0.60
Feb	0.66	0.63	0.62	0.61
Mar	0.65	0.61	0.60	0.59
Apr	0.67	0.65	0.66	0.64
May	0.68	0.67	0.70	0.67
Jun	0.68	0.68	0.70	0.67
Jul	0.67	0.65	0.66	0.63
Aug	0.67	0.66	0.67	0.65
Sep	0.68	0.67	0.69	0.66
Oct	0.68	0.68	0.72	0.69
Nov	0.68	0.67	0.72	0.68
Dec	0.67	0.63	0.67	0.64

IV. CONCLUSION

The work presented above provides the global and diffuse solar radiation estimations by employing sunshine hours of the location. A detailed analysis of global solar radiation values measured by a number of methods using the Angstrom equation is presented. These are also compared with the 22-year measured values obtained from NASA. Results indicate that using concentrating solar collectors can be advantageous in these cities. The values acquired from the Clearness Index confirm clear sky conditions and show that the amount of solar radiation on a horizontal surface is sufficient for solar energy utilization in Dubai and Sharjah, U.A.E throughout the year. Both Dubai and Sharjah observed rainfall from the months of December to March. Dubai observed its maximum rain fall in the month of February (25 mm) whereas Sharjah observed its maximum rain in the month of March (38 mm). For Dubai, the highest average maximum and minimum monthly temperatures were 41.3^{o}C and 30^{o}C in the month of August. The highest average maximum and minimum monthly temperatures, for Sharjah, were 42.4^{o}C and 27.9^{o}C in the month of July. The estimation of diffuse radiation from Page and Liu and Jordan methods are in very good agreement. The Diffuse and Beam radiation provide essential information regarding solar energy available as an energy source. The highest monthly beam radiation was measured in the month of June whereas the highest monthly diffuse radiation was measured in the month of July for both the cities. Consequently, results indicate that solar energy has bright prospects in these cities. Ultimately, the wind energy is also an additional prospective in Dubai and Sharjah. A combination of both solar and wind has tremendous potential for the use as a ‘clean, green’ alternate power resource.

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TABLE IV (A)
SOLAR RADIATION DATA FOR DUBAI USING *H* FROM THE REGRESSION CONSTANTS OBTAINED FROM [3]

Months	H_0 MJ/m^2	H MJ/m^2	K_T $=H/H_0$	H_d/H (PAGE)	H_d (PAGE) MJ/m^2	H_d/H (L&J)	H_d (L&J) MJ/m^2	D/H	D/H_0
Jan	23.99	16.05	0.67	0.24	3.92	0.24	3.86	0.24	0.16
Feb	28.13	18.86	0.67	0.24	4.57	0.24	4.51	0.24	0.16
Mar	32.90	21.79	0.66	0.25	5.48	0.25	5.35	0.25	0.16
Apr	36.97	25.04	0.68	0.23	5.87	0.23	5.85	0.23	0.16
May	39.16	26.73	0.68	0.23	6.11	0.23	6.13	0.23	0.16
Jun	39.80	27.15	0.68	0.23	6.22	0.23	6.24	0.23	0.16
July	39.35	26.59	0.68	0.24	6.29	0.24	6.25	0.24	0.16
Aug	37.68	25.56	0.68	0.23	5.97	0.23	5.95	0.23	0.16
Sept	34.25	23.36	0.68	0.23	5.36	0.23	5.37	0.23	0.16
Oct	29.46	20.14	0.68	0.23	4.58	0.23	4.60	0.23	0.16
Nov	24.92	17.03	0.68	0.23	3.88	0.23	3.89	0.23	0.16
Dec	22.76	15.32	0.67	0.24	3.67	0.24	3.63	0.24	0.16

TABLE IV (B)
SOLAR RADIATION DATA FOR SHARJAH USING *H* FROM THE REGRESSION CONSTANTS OBTAINED FROM [3]

Months	H_0 MJ/m^2	H MJ/m^2	K_T $=H/H_0$	H_d/H (PAGE)	H_d (PAGE) MJ/m^2	H_d/H (L&J)	H_d (L&J) MJ/m^2	D/H	D/H_0
Jan	23.97	15.63	0.65	0.26	4.11	0.25	3.97	0.26	0.17
Feb	28.11	18.49	0.66	0.26	4.75	0.25	4.61	0.25	0.17
Mar	32.89	21.30	0.65	0.27	5.71	0.26	5.48	0.26	0.17
Apr	36.96	24.84	0.67	0.24	5.98	0.24	5.91	0.24	0.16
May	39.16	26.64	0.68	0.23	6.16	0.23	6.16	0.23	0.16
Jun	39.80	27.09	0.68	0.23	6.26	0.23	6.26	0.23	0.16
July	39.36	26.37	0.67	0.24	6.40	0.24	6.32	0.24	0.16
Aug	37.68	25.42	0.68	0.24	6.04	0.24	5.99	0.24	0.16
Sept	34.24	23.26	0.68	0.23	5.40	0.23	5.40	0.23	0.16
Oct	29.44	20.04	0.68	0.23	4.63	0.23	4.63	0.23	0.16
Nov	24.89	16.89	0.68	0.23	3.94	0.23	3.93	0.23	0.16
Dec	22.73	15.01	0.66	0.25	3.81	0.25	3.71	0.25	0.17

TABLE V
STATISTICAL DATA FOR GLOBAL SOLAR RADIATION FOR DUBAI AND SHARJAH

	Dubai	Sharjah
Jan-Mar	67%	65%
Apr-Jun	68%	68%
Jul-Sep	68%	67%
Oct-Dec	68%	67%

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