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DEVELOPING EMPIRICAL MODELS FOR ESTIMATING GLOBAL SOLAR RADIATION IN GAZA STRIP, PALESTINE

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Abstract: Recently, with the critical situation of siege on Gaza Strip, the need of alternative energy source instead of traditional energy sources becomes increasing day by day. Meanwhile, solar energy suggests it's self as a promising renewable energy source for Palestine as it is considered one of the sunny countries and percepts good solar radiation over the year. In this study, Angstrom-type polynomial of first and second order have been developed from long term records of monthly mean daily sunshine of several stations near Gaza Strip. The estimated radiation from the developed model is compared with the measured one.

Keywords; Solar Radiation, Angstrom-type polynomial, Solar model.

التحكم بتصميم وتحديث نموذج امبركل لتقدير الإشعاع الشمسي الساقط على قطاع غزة

ملخص: في الآونة الأخيرة، ومع الوضع الحرج للحصار الظالم على قطاع غزة، ظهرت الحاجة للطاقة البديلة عن مصادر الطاقة التقليدية وأصبح الطلب عليها يتزايد تدريجياً. الطاقة الشمسية تطرح نفسها وبقوة كمصدر واعد وبديل للطاقة خاصة أن فلسطين تعتبر من المناطق المشمسة و التي تستقبل إشعاع شمسي بشكل جيد على مدار السنة. في هذه الدراسة، متعددة انجستروم من الدرجة الأولى والثانية تم استخدامهم لتطوير قالب خاص بالأراضي الفلسطينية وذلك بالاستعانة ببعض البيانات القديمة -للإشعاع الساقط- من المحطات القريبة لقطاع غزة، وتم بعد ذلك مقارنة بيانات هذا القالب مع البيانات القديمة والمقاسة من قبل المحطات سابقاً.

I. INTRODUCTION

Palestine is located within the solar belt countries and considered as one of the highest solar potential energy, the climate conditions of the Palestinian Territories are predominantly very sunny with an average solar radiation on a horizontal surface about 5.4 kWh/m^2.day [1].

The Gaza Strip is 360km^2 with a high density population of about 4,118 persons/km^2 [2], so The Gaza Strip represents one of the most densely populated areas in The Middle East. As the population in The Gaza Strip increases (population growth rate 3.349%/year [3]), the consumption of water and energy will increase; leading to significant rise in unacceptable levels of air pollution, and the defect in water supply and energy sources will increase; leading to severe economical crisis that will result in a significant rise in the probability of an outbreak of warfare.

On the other hand, The Gaza Strip has suffered from mandatory siege since 2006 by Israeli Occupation after Palestinian election, which result in several problems for Power Generation Sector, they faced several obstacles beginning with destroying main generators of Gaza Power Plant in June 2006 [4] through blocking fuel entry into Palestinian Territories in 2008 [5] ending to unknown and horrible situation.

For all previous reasons, using renewable energy has become a global and national trend, so the need of alternative and urgent power source to supply hospitals and medical centers is very important issue especially in situation as it in Gaza Strip; imposed siege, shortage in fuel supplies, and increasing in the mortality rate.

The objective of this study to develop an empirical global solar radiation model using a simple meteorological data obtained from nearest centers of Gaza Strip.

II. BACKGROUND

Understanding solar radiation data and the amount of solar energy intercepts specific area are essential for modeling solar energy system and covering the demand. Therefore, precise knowledge of historical global solar radiation at a location of study is required for the design of any funded solar energy project.

Unfortunately, no meteorological stations available in The Gaza Strip to measure the amount of intercepted solar radiation. So an alternative method for estimation of solar radiation is required.

Several studies on modeling solar radiation have been done in Tunis [6], Bangladesh [7], Rwanda [8], Pakistan [9] and other developing countries. All of these studies used historical meteorological data of the location for estimating the empirical model. Empirical models are classified into three categories: sunshine-based model, temperature-based model and cloud based models [8].

Sunshine based models are the most widely used, which use only bright sunshine hours as input parameter while others use additional meteorological data together with bright sunshine hours.

In this study, Angstrom-type polynomials of first and second order have been developed for estimating the global solar radiation in Gaza Strip, Palestine from a long term records of monthly mean daily sunshine hour values and measured daily global solar radiation on horizontal surface at several locations near The Gaza Strip or have the same climate conditions. The coefficients are derived by using least square regression analysis using MATLAB. These coefficients are generally valid for estimating the radiation in Gaza Strip, Palestine.

III. METHODOLOGY

A. Data:

In Gaza Strip, recorded global solar radiation data on horizontal surface were obtained from several stations around The Gaza Strip as shown in Figure 1. According to Ref. [10] the solar radiation level for both areas The Gaza Strip and Bet Dagan are similar.

Table 1 presents the location of stations and the period of observation for which global solar radiation H_g and sunshine duration L_t were measured.

TABLE 1. LOCATION OF STATIONS AND PERIOD OF OBSERVATION OF GLOBAL SOLAR RADIATION

Station	Altitude (ft)	Latitude (N)	Longitude (E)	*Duration* From year – to year
Bet Dagan	120	32° 00`	34° 49`	1991-2005
Al-Arish[a]	75	31° 08`	33° 48`	1981-2000
Rafah[b]	114	31° 17`	34° 14`	1981-2000
BenGurion Airport[c]	145	32° 00`	34° 52`	1981-2000

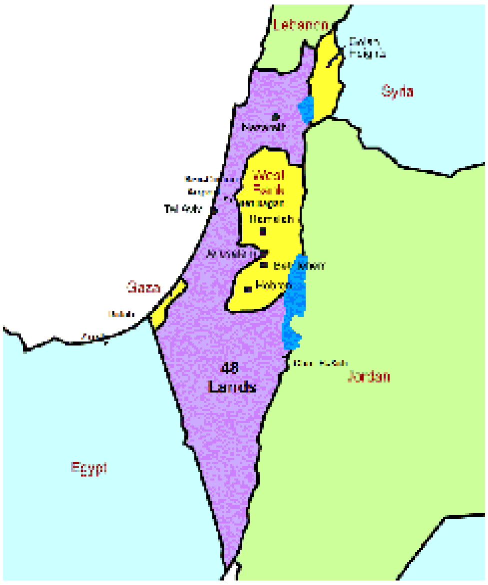

Figure 1: Location of Stations that record Global Solar Radiation

Description of the Model:

The model is based on 14 years of data (1991-2005) and 20 years of data (1981-2000) from Bet Dagan and METEOTEST Software respectively.

Angstrom's equation [11] is used to express the average radiation on a horizontal surface in terms of constants α_1, α_2 and the observed values of average length of solar days. The constants α_1, α_2 will be determined for this model based on actual old measurements and equating the data in the Angstrom's equation given as follows:

$$\frac{H_g}{H_c} = \alpha_1 + \alpha_2 \left(\frac{L_k}{L_m}\right) \qquad .1$$

Where

L_k is the average length of solar day for a given month calculated/observed.

L_m is the length of the longest day in the month.

α_1, α_2 are the average length of solar day for a given month calculated/observed.

H_g is the monthly average of daily global radiation on the horizontal surface at a particular location.

H_c is the maximum monthly average of daily global radiation per day corresponding to clear sky

DEVELOPING EMPIRICAL MODELS FOR ESTIMATING

Values of L_m or Day Length (*DL*) are computed from Cooper's formula [12] as follows:

$$L_m = \left(\frac{2}{15}\right)\omega_s \quad . \ .$$

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad . \ .$$

Where

ω_s is the Sunshine Hour Angle

ϕ is the latitude of the location. (31° 27' for Gaza)

δ is the solar declination angle, which defined as the angle between the line joining centers of the sun and earth and the equatorial plane.

Values of δ are computed from the following relation [11],

$$\delta = 23.45\,\sin\left(\frac{360\,(284+n)}{365}\right) \quad . \ .$$

Where

n is the day of the year, it is usually calculated in the 15^{th} of each month.

Back to equation (1), H_c is replaced with H_o according to changes done on modified Angstrom's Equation for Daily Global Radiation, where H_o is the Daily extra-terrestrial radiation, mean value for the month, which computed by the following relationship in [11]:

$$H_o = \frac{24}{\pi}\, I_{sc}\left(1 + 0.33\cos\frac{360n}{365}\right)(\omega_s \sin\phi\sin\delta + \cos\phi\cos\delta\sin\omega_s) \quad . \ .$$

Where

I_{sc} is the Solar Constant (1353 kW/m^2 = 4870.8 $kJ/m^2.hr$)

Using the data of Global Radiation H_g and the average length of solar day L_m around the location of Gaza Strip, the regression constants of Angstrom's Equation α_1, α_2 could be obtained using MATLAB.

The Second order polynomial of Angstrom's Equation developed in [9] is also used in this paper to be modeled for our case in Gaza Strip, Palestine.

$$\frac{H_g}{H_o} = \alpha_3 + \alpha_4\left(\frac{L_k}{L_m}\right) + \alpha_5\left(\frac{L_k}{L_m}\right)^2 \quad . \; .$$

Where

$\alpha_3, \alpha_4, \alpha_5$ are the Angstrom's Constants

B. ***MATLAB Program:***

The regression constants $\alpha_1, \alpha_2, \ldots, \alpha_5$ have been obtained using MATLAB program which employs the robust least square regression technique. *SSE, RMSE, R^2 and Adjusted- R^2* are calculated to assess the validity of estimation, and also to compare between two types of Angstrom's Equation.

IV. RESULTS AND DISCUSSION

Linear and polynomial least square regression techniques were implemented using the observed metrological data at Bet Dagan and METEOTEST Software as given in Table 2

TABLE 2. INPUT PARAMETERS FOR ANGSTROM'S EQUATIONS

Locat.	***From Equ. (2), (5)***		***Bet Dagan***	***METEO-TEST***	***Average of Observed Values***	
Month	H_o	L_m ***(hrs)***	H_g	H_g	H_{avg} ***(kWh/m²·d)***	L_h ***(hrs)***
Jan	7.05	10.79	2.61	3.24	2.9240	6
Feb	8.16	11.27	3.4	4.01	3.7035	7
Mar	9.36	11.85	4.7	5.32	5.0086	7.5
Apr	10.39	12.51	5.86	6.34	6.1019	9
May	10.87	13.05	6.88	7.20	7.0417	10.5
Jun	10.98	13.34	7.55	7.65	7.6014	12
Jul	10.9	13.22	7.29	7.80	7.5458	12
Aug	10.55	12.76	6.67	7.16	6.9133	11.5
Sept	9.73	12.12	5.69	6.29	5.9922	10
Oct	8.52	11.48	4.25	4.94	4.5964	9
Nov	7.31	10.92	3.09	3.89	3.4922	7
Dec	6.73	10.66	2.48	3.03	2.7525	6

Figure 2 shows the clearness index for Gaza Strip, Palestine. The curve indicates that The Gaza Strip has clear sky condition most of the year, and the clearness index has maximum values on Jun-Aug with maximum sunshine hours, which implies that the maximum utilization of solar energy will be in summer.

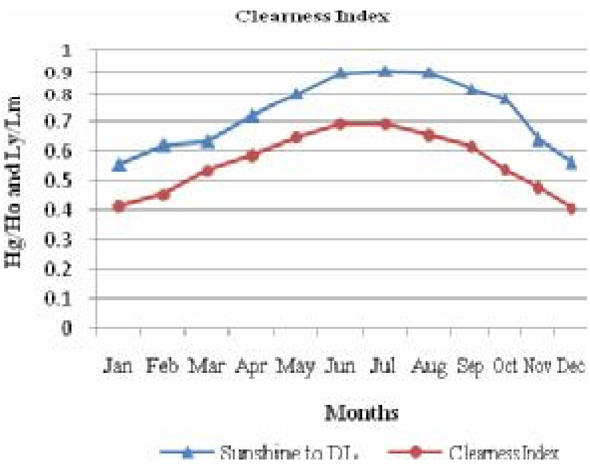

Figure 2: The Clearness Index for Gaza Strip, Palestine

The computed values for regression coefficients are

$$\alpha_1 = -0.002351, \alpha_2 = 0.7607, \alpha_3 = -0.3941, \alpha_4 = 1.868, \alpha_5 = -0.7551.$$

So the first and second order Angstrom's Equation are then given respectively by:

$$\frac{H_g}{H_o} = -0.002351 + 0.7607\left(\frac{L_k}{L_m}\right) \quad . \ .$$

$$\frac{H_g}{H_o} = -0.3941 + 1.868\left(\frac{L_k}{L_m}\right) - 0.7551\left(\frac{L_k}{L_m}\right)^2 \quad . \ .$$

The comparison between the estimated values using the previous equations [7] and [8] respectively, with the observed values are given in Table 3.

TABLE 3. COMPARISON BETWEEN THE OBSERVED AND ESTIMATED BLOBAL SOLAR RADIATION FOR GAZA STRIP

Locat.	**Estimated** H_g **(kWh/m^2.d)**		**Observed** H_g **(kWh/m^2.d)**		**Old Model**
Month	***Linear***	***Polyn.***	***Bet Dagan***	***METEO-TEST***	***Gaza Station***
Jan	2.9660	2.8986	2.61	3.24	2.70
Feb	3.8345	3.8729	3.4	4.01	3.12
Mar	4.4872	4.5492	4.7	5.32	3.67
Apr	5.6604	5.8064	5.86	6.34	4.25
May	6.6238	6.7365	6.88	7.20	4.87
Jun	7.4911	7.4170	7.55	7.65	5.27
Jul	7.4984	7.4029	7.29	7.80	5.35
Aug	7.2059	7.1305	6.67	7.16	5.18
Sept	6.0819	6.1579	5.69	6.29	4.67
Oct	5.0650	5.1693	4.25	4.94	3.87
Nov	3.5474	3.6040	3.09	3.89	2.94
Dec	2.8660	2.8138	2.48	3.03	2.61

Figure 3 shows the small difference between the estimated and the observed values, while the old model of Gaza Station [13] has a huge gap between their results and the results of the developed model. Also there is a difference between their model and the observed data of Bet Dagan itself, where they used its metrological data for modeling.

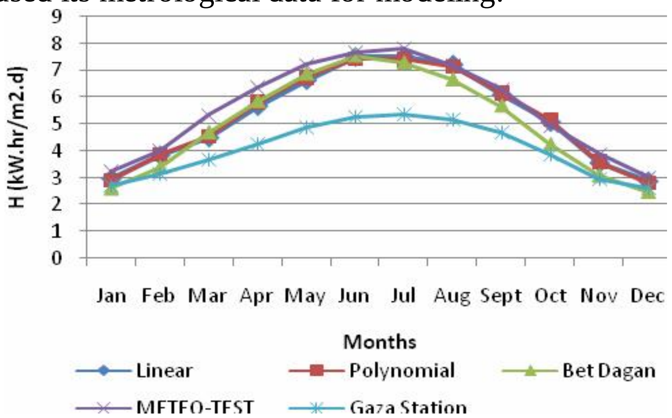

Figure 3: Comparison between the estimated and the observed values

The deviations between the estimated values of the developed model and the observed global solar radiation data are given in Table 4, *SSE*, R^2 and *RMSE* are calculated using [14].

As shown in Table 4, the linear model has the best results when compared with Bet Dagan Station; while the polynomial model has the best results when compared with METEOTEST Station. Both models have fine agreement between measured and estimated values. While both linear and polynomial models are not suitable for old Gaza station model, which indicates low accuracy of this model.

TABLE 4. DEVIATIONS BETWEEN THE ESTIMATED MODEL AND THE OBSEREVD GLOBAL SOLAR RADIATION DATA

Data	***Developed Model***	***SSE***	R^2	***RMSE***	***Mean Square Error (%)***
Bet Dagan	*Linear*	1.9764	0.9492	0.4058	6.69053
	Polynomial	2.0353	0.9478	0.4118	6.90387
Meteo-Test	*Linear*	1.9148	0.9441	0.3995	5.60819
	Polynomial	1.6405	0.9519	0.3697	5.40202
Old Gaza Model	*Linear*	23.8233	0.2070	1.4090	28.3354
	Polynomial	**24.2984**	**0.2064**	**1.4230**	28.6808

As a result, the developed Angstrom's Equations, both first and second order type could be simply applied to estimate monthly average daily global radiation from monthly average daily sunshine hours, which are available in primary station across Gaza Strip, Palestine.

V. CONCLUSION

The development of the Angstrom's Equation for Gaza Strip, Palestine is considered in this study, both types of linear and polynomial type have been developed and tested to measure the fine agreement between the observed and estimated values. From the comparison of these results, it was observed that the estimated values of both models where in a good agreement with both observed values form Bet Dagan and METEOTEST Stations, which strength the developed model, and could be easily applied to Gaza Strip, Palestine. It is worth mentioning that the accuracy of the estimated design model is about 94%, while the mean percentage error is about 6% for both linear and polynomial models, which proves that developed empirical model is very efficient.

VI. ACKNOWLEDGMENT

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