SOLAR ENERGY AVAILABILITY IN SUEZ CANAL'S ZONE - CASE STUDY: PORT SAID AND SUEZ CITIES, EGYPT

G. E. HASSAN [1,2], M. A. ALI [1,*], M. E. YOUSSEF [1]

[1]*Informatics Research Institute, City For Scientific Research And Technological Applications, New Borg El Arab City, 21934, Alexandria, Egypt*

[2] *Mechanical Engineering Department, College Of Engineering And Technology Arab Academy For Science, Technology And Maritime Transport, Alexandria, Egypt*

[*] *Corresponding Author: email: Mohd.Abdelfatah87@Gmail.Com*.

ABSTRACT: Accurate information of solar radiation data is considered as the first process in the solar energy availability assessment. Due to the unavailability of the solar radiation measurements data for different locations around the world, different solar radiations models are presented for estimating the solar radiation. This study aims to evaluate the solar radiation availability with high accuracy at new Egypt's locations using the mostly simple solar radiation model. The long-term global solar radiation data (33-years) at Port Said and Suez cities are employed for utilized for establishing and validating the developed model. The prediction of the developed model is compared with the measured data and the mostly statistical indicators are computed to evaluate the performance of the established model. The results showed that the proposed solar models in this work donate good prediction for the monthly average daily global solar radiation on a horizontal surface. Consequently, the proposed model is the recommended model to compute global solar radiation on a horizontal surface with high accuracy. In addition, it can be employed in the design and evaluation of performance for various solar energy applications.

Keywords: Solar energy; Solar radiation; Statistical indicators; Empirical models; Egypt

INTRODUCTION

Nowadays, there are a growing interest with different renewable energy sources. Accurate information of solar radiation data is considered as the first process in the solar energy availability assessment [1–7]. Due to the absence of the solar radiation measurements data for various locations around the world, several solar radiations models are introduced for predicting the solar radiation [1,8]. The solar radiation models that depend on meteorological information are the most commonly examined and widely used solar models around the world[9]. Å ngströ m [10] presented the primary solar model which based on sunshine data. Hargreaves and Samani[11] proposed a simple model based only on minimum and maximum air temperatures to estimate the solar radiation. Annandale et al. [12] modified Hargreaves and Samani's model [11] to calculate the effects of decreased altitude and atmospheric thickness on global solar radiation. The performance of 31 non-sunshine-based solar radiation models for estimating the monthly average of daily global solar radiation on a horizontal surface was carried out by Youssef et al. [13]. The obtained results illustrated that Toğrul's[14] and Ertekin's[15], models have the best estimations. Similarly, a study of assessment the performance of various global solar radiation models case study New Borg El-Arab city, Egyptwas performed by Hassan et al [16]. Besharat et al. [9] evaluated applicability of available empirical models to predict the monthly average daily global solar radiation on a horizontal surface in Yazd, Iran. The results showed that El-Metwally's[17] model gives the best estimation. Hassan et al. [18] also introduced Seventeen new ambient-temperature-based solar models to estimate global solar radiation as alternatives to the widely used sunshine-based solar models due to the absence of sunshine data at the most sites around the world. These proposed solar models are established, validated and compared with other three models presented in the literature to evaluate the monthly average daily global solar radiation on a horizontal surface. The results demonstrated that the local formula for the most accurate model new model (Hassan [18] Model6) has best estimation for global solar radiation at various sites, particularly at coastal sites.

In this consider, this study purpose to evaluate the solar radiation availability at new Egypt's locations with high accuracy using the mostly simple solar radiation model. The long-term global solar radiation data (33-year) at Port Said city and Suez city are employed for establishing and validating the developed model. The performance of the established models are validated and compared with the measured data of global solar radiation at selected sites. The geographical locations for Port Said city and Suez city are Lat. Lat. 31° 17` N and long . 32° 28` E, and Lat . 29° 58` N and long . 32° 33` E, respectively. The statistical indicators; coefficient of determination (R^2) and root mean square error (RMSE) are calculated to evaluate the performance of the model [9,19].

Figure. 1 The selected locations of the study[20].

MATHEMATICAL MODEL

In general, this study used a newly introduced temperature-based model [18] to estimate solar radiation where there is no instrument for predicting solar radiation. As well, ambient temperature data are already recorded, this considers to be the main advantage of this model in the current study. This model was suggested by Hassan et al. [18], and it is defined as:

$$G/G_0 = a\,T^b G_0 + c \qquad (1)$$

where G, and G_0, T are monthly average daily global solar radiation on a horizontal surface (MJ/m^2 day^{-1}), monthly average daily extra-terrestrial solar radiation on a horizontal surface (MJ/m^2 day^{-1}) and the monthly averages of daily ambient temperature (˚C), respectively. *a*, *b* and *c* are the empirical coefficients.

EVALUATION APPROACH

The performance of the established models are evaluated using the mostly common statistical indicators, namely; root mean square error (RMSE) and coefficient of determination (R^2) [9,13,18]. The values of RMSE error are between ±10% is considered the acceptable values, and values of R^2 are between zero and one ($0 \leq R^2$ and $r \leq 1$) [21]. Coefficient of determination values give information about the goodness of fit of the model. The largest values of coefficient of determination are the desired value. The values of RMSE donate information about the short-term performance of the model. Its values (RMSE) are always positive values, the smaller values point to better performance of the model, and zero represent the ideal case. They are defined as:

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(G_{i.c} - G_{i.m})^2\right]^{1/2} \qquad (2)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(G_{i.m} - G_{i.c})^2}{\sum_{i=1}^{n}(G_{i.m} - \overline{G_m})^2} \qquad (3)$$

where$G_{i.c}$ is the i th estimated value, and $G_{i.m}$is the ith measured value. $\overline{G_m}$is the average value of the measured and estimated values; and$n$ is the number of observations.

DATA COLLECTION

To achieve study goal, the long-term of the measured data (ambient temperature and global solar radiation data) for 33 years between 1 July 1983 and 31 December 2016 are utilized to establish and validate the applicability of the developed model to estimate the monthly average daily global solar radiation on a horizontal surface. These data were obtained from the NASA Surface meteorology and Solar Energy website [18,22–24]. The values of the extra-terrestrial solar radiation are computed [18], and the monthly average values of daily global solar radiation , temperature and extra-terrestrial solar radiation are calculated using an in-house computer program developed using the C# language.

RESULTS AND DISCUSSION

The measured data of daily global solar radiation and ambient temperature are divided into two subsets and averaged to get the monthly average daily values. The first subset is from 1 July 1983 to 31 December 2014, and it is utilized to establish models using regression analysis [9,21]. Empirical coefficients values are computed and introduced in **Table 1**. The second subset is from 1 January 2015 to 31 December 2016, and it is employed to evaluate and validate the established model using statistical indicators; RMSE and R^2. The predicted values of developed models are compared with the measured data of global solar radiation of selected locations based on RMSE and R^2

values. These statistical indicators are calculated using equations Eqs. (2) and (3), and summarized in **Table 1**.

According to the comparison results with the measured data of global solar radiation, the proposed models provided well performance, with RMSE error values in the acceptable range ±10%. As well, the performance of the model showed good R^2 values, which refers to good fitting between models predictions and measured values. Moreover, the values of coefficient of determination, (R^2), at two cities are very good values and greater than 91%. Where, the values of RMSE and $R^2$for Port Said city are 1.91 MJ/m^2 day^{-1} and 0.91 %, as well as 0.89 MJ/m^2 day^{-1} and 0.98 % for Suez city. **Figure 1** shows the performance of the presented modelagainst the measured data at two selected cities (Port Said city and Suez city).

As illustrated in **Figure 1**, the prediction of the developed models is closed to the measured values, with a slightly overestimation at Port Said city especially at the first half of the year. The low performance of the model at Port said city due to different weather condition specially at coastal sites such as Port Said city [25]. Based on the comparison between the model prediction and the measured data of global solar radiation, the formulas of the introduced model give accurate estimation as demonstrated by the statistical performance in **Table 1**. Graph of the statistical performance of developed models at two cities is presented in **Figure 2**. It is clearly illustrated that the proposed formulas of the proposed model have well values for statistical indicators.Therefore, the proposed model (Eq. 1) [18] proved to be the recommended model for predicting global solar radiation on a horizontal surface with high accuracy at different sites. Of more interest, the diagram for the whole process of establishing and validating models is explored in **Figure 3**.

Table 1 Empirical coefficients and statistical indicators for selected cities.

City	a	b	c	RMSE	R^2
Port Said	0.00034	0.83609	0.51841	1.91	0.91
Suez	0.00082	0.52864	0.51990	0.89	0.98

Furthermore, by using the proposed formulas of the developed model, predictions solar radiation can be easily accomplished with sufficient reliability at different sites where there is no instruments for measuring solar radiation, especially in developing countries. Where temperature information is already recorded and continuously for other aims, this is considered the main benefit of the introduced model in the present work. Moreover, the high applicability of the ambient temperature-based solar models can be achieved by coupling the developed models with different weather forecast techniques that are mainly employed to accurately forecast the weather temperature. Using these accurate future predictions for ambient temperature as inputs to the developed models in this study to predict the accurate future predictions for solar radiation can be considered as a valuable tool for future design and performance analysis for different solar energy systems.

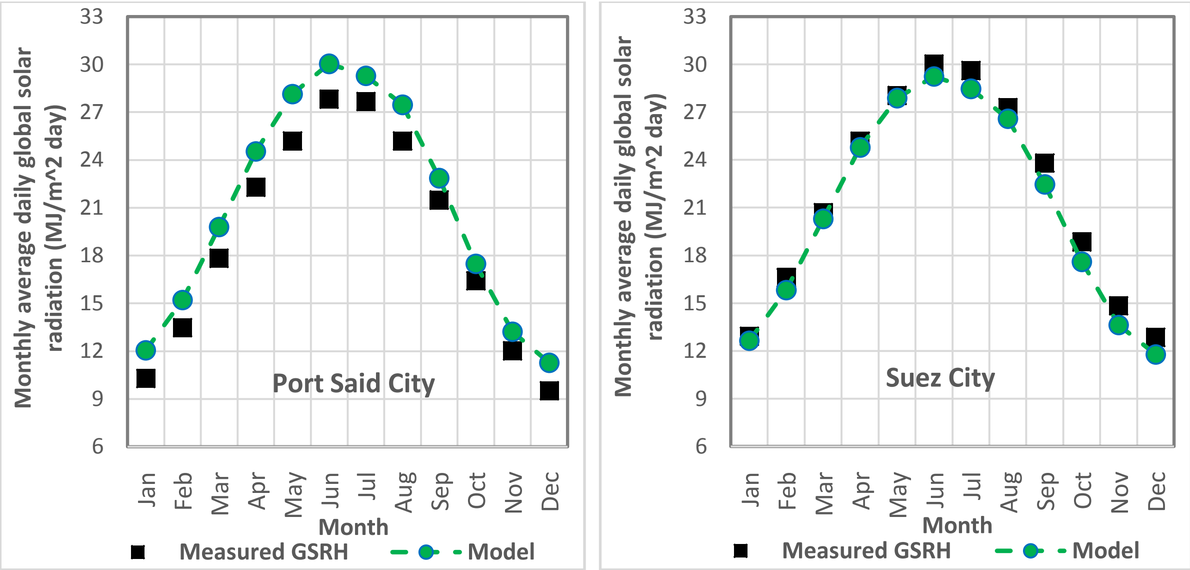

Figure. 1 Overall performance of the developed models at Port Said city and Suez city, Egypt.

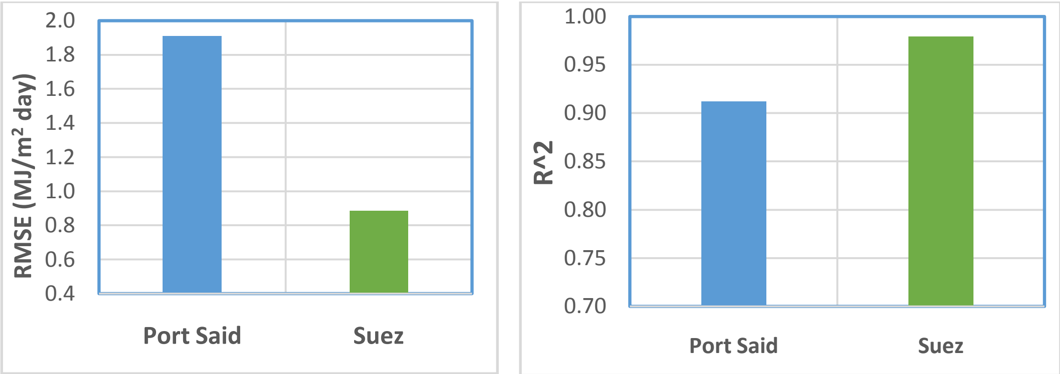

Figure. 2 Statistical indicators graph for the solar model at Port Said city and Suez city.

From the above results, it can be concluded that the proposed model in this work can be utilized for predicting global solar radiation with higher accuracy. Moreover, the obtained results from this work are consistent with the results of previous studies [18], which conclude that the Hassan Model [18] (Eq. 1) has accurate estimation for global solar radiation on a horizontal surface. Therefore, it is the recommended model to predict global solar radiation on a horizontal surface in different locations with high accuracy. Hence, these accurate estimations for global solar radiation can be considered to be a valuable appliance for design and evaluation of performance of different solar applications in the future.

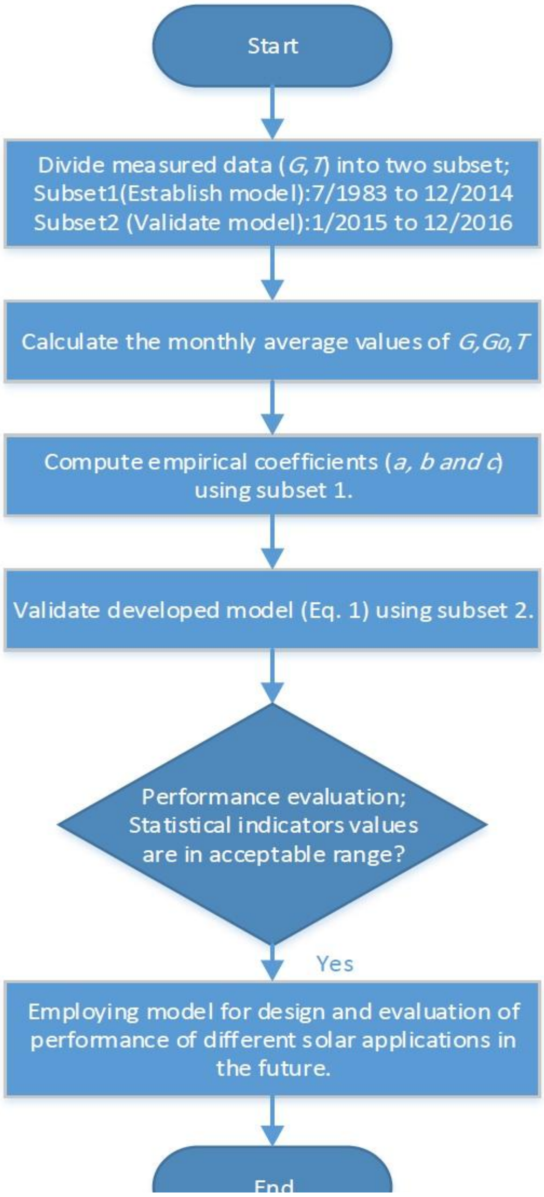

Figure.3 the diagram for the whole Process of the establishing and validating models.

CONCLUSIONS

The current study aims to evaluate the solar radiation availability at new Egypt's locations with high accuracy using the mostly simple solar radiation model. The long-term global solar radiation data over a 30-year at Port Said city and Suez city are used for utilized for establishing and validating the developed model. The values of the extra-terrestrial solar radiation and monthly average values of measured data (daily global solar radiation and ambient temperature) are calculated using an in-house computer program developed using the C# programing language. The results showed that the formulas of the model at two selected locations have accurate estimation for monthly average daily global solar radiation on a horizontal surface.Moreover, the high applicability of the proposed model, which can be accomplished by coupling it with different temperature weather forecast methods. Therefore, the presented model (Hassan Model, Eq. 1) is the recommended model to predict global solar radiation on a horizontal surface in different locations with high accuracy. It is believed that, the accurate estimation of global solar radiation from this approach can be considered to be a valuable appliance for design and evaluation of performance of different solar applications in the future.

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REFERENCES

1. Ali MA, Hassan GE, Youssef ME. Assessment the Performance of Artificial Neural Networks in Estimating Global Solar Radiation. Int. Conf. New Trends Sustain. Energy-ICNTSE, Pharos University and KTH VETENSKAP OCH KONST; 2016, p. 148–50.
2. Aziz AN, Rabhy OO, Youssef ME. Modeling and Experimental investigation for PEMFC to achieve high Fuel Cell performance. Int. Conf. New Trends Sustain. Energy-ICNTSE, Pharos University and KTH VETENSKAP OCH KONST; 2016, p. 228–31.
3. Hassan GE, Salah AH, Fath H, Elhelw M, Hassan A, Saqr KM. Optimum operational performance of a new stand-alone agricultural greenhouse with integrated-TPV solar panels. Sol Energy 2016;136:303–16.
4. Despotovic M, Nedic V, Despotovic D, Cvetanovic S. Review and statistical analysis of different global solar radiation sunshine models. Renew Sustain Energy Rev 2015;52:1869–80.
5. Hassan G, Salah A, Elhelw M, Hassan A, Fath H, Hassan GE. Development Of A Novel Solar Driven Agriculture Greenhouse□ : Self Sufficient Of Energy And Irrigating Water. Int. Desalin. Assoc. World Congr. Desalin. Water Reuse, 2015, p. 1–10.
6. Kandpal TC, Broman L. Renewable energy education: A global status review. Renew Sustain Energy Rev 2014;34:300–24.
7. Salah AH, Hassan GE. Performance Improvement of Roof Transparent Solar Still Coupled With Agriculture Greenhouse. Int. Conf. New Trends Sustain. Energy-ICNTSE, Pharos University and KTH VETENSKAP OCH KONST; 2016, p. 151–4.
8. El-Sebaii a. a., Al-Hazmi FS, Al-Ghamdi a. a., Yaghmour SJ. Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia. Appl Energy 2010;87:568–76.
9. [9] Besharat F, Dehghan A a., Faghih AR. Empirical models for estimating

global solar radiation: A review and case study. Renew Sustain Energy Rev 2013;21:798–821.

10. Ångström A. Solar and terrestrial radiation. Q J R Meteorol Soc 1924;50:121–5.
11. Hargreaves GH, Samani ZA. Estimating Potential Evapotranspiration. J Irrig Drain Div 1982;108:225–30.
12. Annandale J., Jovanovic N., Benadé N, Allen R. Software for missing data error analysis of Penman-Monteith reference evapotranspiration. Irrig Sci 2002;21:57–67.
13. Youssef E, Hassan GE, Ali MA. Investigating the performance of different models in estimating global solar radiation. Adv Nat Appl Sci 2016;10:379–89.
14. Türk Toğrul I, Onat E. A study for estimating solar radiation in Elaziğ using geographical and meteorological data. Energy Convers Manag 1999;40:1577–84.
15. Ertekin C, Yaldız O. Estimation of monthly average daily global radiation on horizontal surface for Antalya (Turkey). Renew Energy 1999;17:95–102.
16. Gasser E. Hassan, M. Elsayed Youssef, Mohamed A. Ali, Zahraa E. Mohamed AH. Performance assessment of different global solar radiation models case study New Borg El-Arab city, Egypt. Therm Sci 2016:Accepted.
17. El-Metwally M. Sunshine and global solar radiation estimation at different sites in Egypt. J Atmos Solar-Terrestrial Phys 2005;67:1331–42.
18. Hassan GE, Youssef ME, Mohamed ZE, Ali MA, Hanafy AA. New Temperature-based Models for Predicting Global Solar Radiation. Appl Energy 2016;179:437–50.
19. Li H, Ma W, Lian Y, Wang X. Estimating daily global solar radiation by day of year in China. Appl Energy 2010;87:3011–7.
20. Wonderfulnature. Suez Canal's Map. Wonderful Nat Website n.d. http://wonderfulnature.ru/photo/Suez_channel/20.jpg (accessed January 1, 2017).
21. Ajayi OO, Ohijeagbon OD, Nwadialo CE, Olasope O. New model to estimate daily global solar radiation over Nigeria. Sustain Energy Technol Assessments 2014;5:28–36.
22. NASA Data. NASA Surface meteorology and Solar Energy n.d. https://eosweb.larc.nasa.gov/cgi-bin/sse/daily.cgi & https://power.larc.nasa.gov/cgi-bin/agro.cgi?email=agroclim@larc.nasa.gov (accessed April 10, 2015).
23. Tadros MTY, Mustafa MAM. Estimation of the Global Horizontal Solar Radiation in Iraq. Int J Emerg Technol Adv Eng 2014;4:587–605.
24. Hassan GE, Youssef ME, Ali MA, Mohamed ZE, Shehata AI. Performance assessment of different day-of-the-year-based models for estimating global solar radiation - Case study: Egypt. J Atmos Solar-Terrestrial Phys 2016;149:69–80.
25. El-Metwally M. Simple new methods to estimate global solar radiation based on meteorological data in Egypt. Atmos Res 2004;69:217–39.