Estimation of the Diffused Solar Irradiation on the Tilted Plane of Photovoltaic Solar Panels

Estimación de la Irradiación Solar Difusa en el Plano Inclinado de Paneles Solares Fotovoltaicos

Estimativa da Irradiação Solar Difusa no Plano Inclinado de Painéis Solares Fotovoltaicos

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Summary. - Solar energy, in the recent decades has gained a great attention due to its clean, simple and easy adaptable process. The effective utilization of solar energy is possible only if proper data of incident solar radiation is available. There are number of solar models based on different climatical factors, for the assessment of radiation on plane and sloped surfaces are available in the literature but the selection of best possible model is a challenging task. Here, different isotropic and anisotropic solar models have been utilized for the estimation of overall radiation incident on the sloped surface in Karachi then estimation was compared with the experimental values. The models selected for this study includes Liu and Jordan, Koronakis, Badescue, Hay and Davies, Temps and Coulson and HDKR. The predicted values and measured values are compared by using different statistical techniques like Mean Absolute Percentage Error (MAPE), Mean Biased Error (MBE), Root Mean Square Error (RMSE) and t-stats. The outcomes revealed that isotropic models are more suitable model than the anisotropic models. Among all models, Badescue is the best suitable model for the estimation of radiations on sloped surfaces with lowest value of MBE, RMSE and t-stats while Temps and Coulson model, on the basis of MAPE, MBE, RMSE and t-stats is the most inappropriate correlation for the assessment of solar radiations on sloped surface. Overall, for the solar radiation estimation on any sloped plane in Karachi isotropic models have shown a good agreement.

Keywords: Solar energy, tilted surface, Karachi, Statistical techniques.

Resumen. - *La energía solar, en las últimas décadas ha ganado una gran atención debido a su proceso limpio, simple y fácilmente adaptable. La utilización eficaz de la energía solar solo es posible si se dispone de datos adecuados de la radiación solar incidente. Hay varios modelos solares basados en diferentes factores climáticos, para la evaluación de la radiación en superficies planas e inclinadas están disponibles en la literatura, pero la selección del mejor modelo posible es una tarea desafiante. Aquí, se han utilizado diferentes modelos solares isotrópicos y*

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anisotrópicos para la estimación de la radiación total incidente en la superficie inclinada de Karachi y luego se comparó la estimación con los valores experimentales. Los modelos seleccionados para este estudio incluyen a Liu y Jordan, Koronakis, Badescue, Hay y Davies, Temps y Coulson y HDKR. Los valores pronosticados y los valores medidos se comparan utilizando diferentes técnicas estadísticas como el error porcentual absoluto medio (MAPE), el error sesgado medio (MBE), el error cuadrático medio (RMSE) y t-stats. Los resultados revelaron que los modelos isotrópicos son un modelo más adecuado que los modelos anisotrópicos. Entre todos los modelos, Badescue es el modelo más adecuado para la estimación de radiaciones en superficies inclinadas con el valor más bajo de MBE, RMSE y t-stats mientras que el modelo de Temps y Coulson, basado en MAPE, MBE, RMSE y t-stats es la correlación más inapropiada para la evaluación de las radiaciones solares en superficies inclinadas. En general, para la estimación de la radiación solar en cualquier plano inclinado en Karachi, los modelos isotrópicos han mostrado una buena concordancia.

Palabras clave: *Energía solar, superficie inclinada, Karachi, Técnicas estadísticas.*

Resumo. *- A energia solar, nas últimas décadas, ganhou grande atenção devido ao seu processo limpo, simples e de fácil adaptação. A utilização efetiva da energia solar só é possível se dados adequados da radiação solar incidente estiverem disponíveis. Existem vários modelos solares baseados em diferentes fatores climáticos, para a avaliação da radiação em superfícies planas e inclinadas estão disponíveis na literatura, mas a seleção do melhor modelo possível é uma tarefa desafiadora. Aqui, diferentes modelos solares isotrópicos e anisotrópicos foram utilizados para a estimativa da radiação total incidente na superfície inclinada em Karachi, então a estimativa foi comparada com os valores experimentais. Os modelos selecionados para este estudo incluem Liu e Jordan, Koronakis, Badescue, Hay e Davies, Temps e Coulson e HDKR. Os valores previstos e os valores medidos são comparados usando diferentes técnicas estatísticas como Erro Percentual Médio Absoluto (MAPE), Erro Viés Médio (MBE), Erro Quadrático Médio Raiz (RMSE) e t-stats. Os resultados revelaram que os modelos isotrópicos são modelos mais adequados do que os modelos anisotrópicos. Entre todos os modelos, Badescue é o modelo mais adequado para a estimativa de radiações em superfícies inclinadas com o menor valor de MBE, RMSE e t-stats, enquanto o modelo Temps e Coulson, com base em MAPE, MBE, RMSE e t-stats é o correlação mais inadequada para a avaliação de radiações solares em superfície inclinada. No geral, para a estimativa da radiação solar em qualquer plano inclinado em Karachi, os modelos isotrópicos mostraram uma boa concordância.*

Palavras-chave: *Energia solar, superfície inclinada, Karachi, técnicas estatísticas.*

Nomenclature

ω_s:	Sunset/Sunrise Hour angle
δ:	Declination angle
β :	Collector angle with horizontal
φ :	Latitude of location
ρ:	Reflectivity of earth
A:	Anisotropic index
$\bar{H}$:	Monthly average daily solar radiations on horizontal surface
$\bar{H}_o$:	Monthly average daily extra-terrestrial solar radiations on horizontal surface
$\bar{H}_b$:	Beam or direct Radiations
$\bar{H}_d$:	Diffuse radiations
$\bar{H}_T$:	Radiation on tilted surface
$\bar{H}_{T,b}$:	Beam or direct radiation on tilted plane
$\bar{H}_{T,d}$:	Diffuse radiation on tilted plane
$\bar{H}_{T,r}$:	Radiations received by the tilted plane after reflecting from the ground
MAPE:	Mean Absolute percentage error
MBE:	Mean Bias Error
N:	Day of the year
R_b:	Geometric factor
RMSE:	Root Mean Square Error
S:	Cloud cover
S_{max}:	Day length

1. Background. - Continuous depletion of fossil fuels and their escalating prices and also their contribution towards the greenhouse gas emissions [1], [2], forcing the developing nations like Pakistan to face not only financial deficit but also the problem of global warming. Pakistan, fulfills its power requirement by consuming around daily 135,201 barrels of oil which is being imported [3] which do not only cause the huge financial deficit but also results in global warming [4], [5]. In this scenario, it is ideal to look for renewable energy-based power generation systems to solve both financial as well as global warming problems.

Different researchers have explored the potential, opportunities and challenges of renewable energy systems like solar, wind, biomass, hydro and geothermal energy systems [6]–[14]. Among all other renewable energy systems, solar energy is considered to be the best because of its availability, simpler operation, minimal capital and operating cost [8], [15]. One can easily utilize solar energy for meeting the energy requirements only if there is a proper measurement of solar data on particular site which is essential for proper designing of solar devices. The solar data recording is time consuming and also causes the huge investment cost [16], [7]. Classification of solar radiations includes extra-terrestrial and terrestrial. Those radiations which are available outside the atmosphere or simply in space are termed as extra-terrestrial radiations, while terrestrial radiations are those that are received on the surface of the earth after passing through the layers of atmosphere. Extra-terrestrial radiations are calculated by using Klein's formula [17] while terrestrial radiations can't be calculated, they can be measured by using radiation measuring instruments or they can be predicted by utilizing various solar radiation empirical correlation [18].

The measurement of terrestrial radiations doesn't only consume a lot of time but also results in huge investment [19]. Alternate of measuring of solar radiation is the prediction of terrestrial radiation using different empirical correlations developed by different researchers. Variety of empirical correlations for estimation of solar radiations are available based on different climatic factors like sunshine hours, cloud cover, highest and lowest ambient temperature, humidity and others [20]. These empirical correlations predict the quantity of solar radiations incident at a particular by using the already measured data for that particular site.

Angstrom model [21] is considered to be the basic regression-based model, used for the prediction of monthly average daily terrestrial radiations on plane surface for a particular site, by considering the extra-terrestrial radiation, day length and average cloud of that particular site. Ahmad and Ulfat [22] have solved the first order as well as second order Angstrom model for the city of Karachi and presented there is only 5% error. It means that Angstrom model is found to be very good in approximating radiations for Karachi.

The terrestrial radiations that fall on any surface are basically composed of two components: beam and diffuse. Angstrom model only predicts the beam radiation. The prediction of diffuse radiation on any plane or horizontal plane is also very important for proper functioning of solar devices like photovoltaics and thermal collector. Solar devices are normally installed to face towards south and at an inclination equal to the location's latitude for maximum capturing of solar radiation [16]. The radiations that fall on tilted surface has three basic components; beam or direct radiation, scattered or diffuse radiation and the reflected radiation from ground. The beam radiation on horizontal surface can be predicted and then transformed on the tilted surface by using the simple geometrical relations. The diffuse radiations can be estimated by using different isotropic and anisotropic models [23]. The intensity of solar radiation in Isotropic models is assumed to be uniformly distributed over the entire sky dome. While anisotropic models assume anisotropy near circumsolar and isotropic in rest of the region. Maleki et al. [24] has reviewed various empirical equations for estimating solar radiations on inclined surfaces of different countries and determined the best possible correlations for the selected countries studied. Shukla et al. [23] has studied different isotropic and anisotropic models for Bhopal city of India, and found that Badescue model is the best suitable model for the approximation of solar radiations on sloped surfaces in Bhopal. Sebaii et al. [20] using statistical techniques evaluated that isotropic model for the approximation of solar radiations on sloped surfaces in Jeddah city gives more accurate results than the anisotropic models.

From above discussions, it is obvious that the adaptation of the most appropriate model for solar radiation estimation on sloped surface for a particular site is necessary to properly utilized the solar radiation. In our previous research [25], Hargreaves model was found to be the best suitable for the approximation of radiation on horizontal surface. In this paper, different isotropic and anisotropic solar models for approximation of solar radiation on tilted surface in Karachi have been studied. The approximation of solar radiation on sloped surface in Karachi from models have been done and compared with the experimental data. Statistical tools like MBE, RMSE, MAPE and t-stats have been used for the selection of the best suitable model for Karachi.

2. Methodology. - The site designated for the research is Karachi having the latitude of 24.86° N and longitude of 67.00° E and is located at the seashore. The average temperature of Karachi is $30^o\ C$ [26]. Overall, the weather of Karachi is hot and humid.

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Figure I.- Study location of Karachi
Source of map: www.pc.gov.pk

The solar declination angle is computed by Coopers' formula [27]

$$\delta = 23.34 \sin\left(\frac{360}{365}(284 + N)\right) \quad (1)$$

Here, N is the average day of the month can be taken from [28].

$$\bar{H}_o = \frac{24}{\pi} \times G_{sc}\left(1 + 0.033\cos\frac{360N}{365}\right) \times \left(\frac{\pi\omega_s}{180}\sin\varphi\sin\delta + \cos\varphi\cos\delta\sin\omega_s\right) \quad (2)$$

Here G_{sc} is known as solar constant $1367\ W/m^2$, ω_s is termed as sunset hour angle, φ is the location's latitude.

From latitude and declination angle, sunset hour angle is calculated by [28]

$$\omega_s = arc\ cos(-\tan\emptyset\ tan\delta) \quad (3)$$

Monthly average daily terrestrial radiation from Angstrom model [21] can be computed by:

$$\frac{\bar{H}}{\bar{H}_o} = a + b\left(\frac{S}{S_{max}}\right) \quad (4)$$

Here S is the average cloud cover and S_{max} is the daylength can be computed by

$$S_{max} = \frac{2}{15}\omega_s \quad (5)$$

The Angstrom model for Karachi was first solved by Ahmed and Ulfat [22]

$$\frac{\bar{H}}{\bar{H}_o} = 0.324 + 0.405\left(\frac{S}{S_{max}}\right) \quad (6)$$

The ration of $\frac{S}{S_{max}}$ for every month is presented in table 1.

Month	S/S_{max}
January	8.05x10^{-1}
February	7.76x10^{-1}
March	7.62x10^{-1}
April	7.38x10^{-1}
May	7.43x10^{-1}
June	5.95x10^{-1}
July	3.81x10^{-1}
August	3.90x10^{-1}
September	6.02x10^{-1}
October	8.18x10^{-1}
November	8.37x10^{-1}
December	8.30x10^{-1}

Table 1. Ratio of $\frac{S}{S_{max}}$ *throughout the year for Karachi*

The overall amount of radiations on any tilted surface is sub divided into direct or beam radiations, diffuse radiations and radiations reflected from ground.

$$\bar{H}_T = \bar{H}_{T,b} + \bar{H}_{T,d} + \bar{H}_{T,r} \qquad (7)$$

Here, $\bar{H}_T$ is the monthly average daily total radiation on sloped surface, $\bar{H}_{T,b}$ is the beam radiation on sloped surface, $\bar{H}_{T,d}$ is the diffuse radiation on sloped surface while $\bar{H}_{T,r}$ is the radiation which is reflected from the ground and received by the sloped plane.

The beam or direct radiation on the tilted plane can be determined from the equation given below:

$$\bar{H}_{T,b} = \bar{H}_b R_b \qquad (8)$$

Here, $\bar{H}_b$ is the monthly average daily direct radiation on horizontal plane and is the difference of overall radiation on horizontal plane and scattered radiation on horizontal plane. R_b is termed as geometric factor and is defined as the ratio of direct radiation on sloped surface to that of the direct radiations on horizontal surface.

$$R_b = \frac{\sin\delta \sin(\emptyset-\beta)+\cos\delta \cos(\emptyset-\beta)}{\sin\delta \sin\emptyset+\cos\delta \cos\emptyset} \qquad (9)$$

Diffuse radiations are that part of total radiation from sun, incident on the earth surface when its direction is changed because of scattering through the atmosphere. The direct solar radiation collides with different molecules present in the atmosphere, and due to tis diffusive reflection of direct radiation, the radiation moves in different direction. These radiations can be received and recorded from sun rise to sunset. However, diffuse radiations are difficult to determine as their direction is highly variable.

Ground reflected radiation are those radiation which fall on the tilted after reflecting from any other surface like ground, trees, building and others. The view factor of the sloped surface facing the ground is $F_{i-g} = {(1-\cos\beta)}/{2}$. The reflected radiation on any sloped surface is given by

$$\bar{H}_{T,r} = \bar{H}\rho\,\frac{1-\cos\beta}{2} \qquad (10)$$

Here, $\bar{H}$ is the overall radiations on horizontal plane and ρ is defined as reflectiveness of ground. For dry soil $\rho = 0.25$, wet soil $\rho = 0.12$, snow cover $\rho = 0.9$ and water surface $\rho = 0.10$ [29]

Several different models for approximation of total radiation available on sloped surface are available. In our study, Liu and Jordan [30], Koronakis [31], Badescue [32], Temps and Coulson [33], Hay and Devies [34] and HDKR [35] have used for the approximation of solar radiations on tilted surface.

The total radiations on sloped surface from Liu and Jordan Model is given by

$$\bar{H}_T = \bar{H}_b R_b + \bar{H}_d\left(\frac{1+\cos\beta}{2}\right) + \bar{H}_g\rho\left(\frac{1-\cos\beta}{2}\right) \qquad (11)$$

Solar radiations on tilted surface from Koronakis model are estimated by

$$\bar{H}_T = \bar{H}_b R_b + \bar{H}_d\left(\frac{2+\cos\beta}{3}\right) + \bar{H}_g\rho\left(\frac{1-\cos\beta}{2}\right) \qquad (12)$$

Total radiations on tilted surface from Badescue model are estimated by

$$\bar{H}_T = \bar{H}_b R_b + \bar{H}_d\left(\frac{3+\cos 2\beta}{4}\right) + \bar{H}_g\rho\left(\frac{1-\cos\beta}{2}\right) \qquad (13)$$

Temps and Coulson model is anisotropic model and solar radiations on any inclined surface are estimated by

$$\bar{H}_T = \bar{H}_b R_b + \bar{H}_d\left\{\left(\frac{1+\cos\beta}{2}\right)\left[1 + sin^3\left(\frac{\beta}{2}\right)\right](1 + cos^2\theta\, sin^3\theta_z)\right\} + \bar{H}_g\rho\left(\frac{1-\cos\beta}{2}\right) \qquad (14)$$

Hay and Devies model estimate the solar radiations on tilted surface by

$$\bar{H}_T = (\bar{H}_b + \bar{H}_d A)R_b + \bar{H}_g \rho \left(\frac{1-\cos\beta}{2}\right) + \bar{H}_d \left(\frac{1+\cos\beta}{2}\right)(1-A) + AR_b \tag{15}$$

Here, A is termed as anisotropic index, and it depends upon the transmittance of atmosphere for beam radiations.

$$A = \frac{\bar{H}_{b,n}}{\bar{H}_{o,n}} = \frac{\bar{H}_b}{\bar{H}_o} \tag{16}$$

2.1 Techniques for model evaluation. -

The approximation of the solar energy (radiation) from the six models mentioned above, for Karachi has been done and then estimation is compared with the experimental data by using following statistical tools,

- MAPE
- MBE
- RMSE
- t-statistics

MAPE is a simple tool which is used to check how accurate the data is by just calculating the percentage of error and is given by:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\bar{H}-\bar{H}_P}{\bar{H}}\right) \times 100 \tag{17}$$

Here $\bar{H}$ is the measured value, $\bar{H}_P$ is the estimation while the total number of set-points is represented by n. The best result for MAPE is considered to be zero.

MBE shows the judgement of the real deviation between mean and estimated results. It gives evidence on longer period presentation and can be calculated by

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(\bar{H} - \bar{H}_P) \tag{18}$$

Here $\bar{H}$ is the experimental value, $\bar{H}_P$ is the predicted one, determined from the empirical equations. Zero is considered to be the ideal value for Mean Biased Error.

RMSE shows the judgement about how much deviation is present between measured and estimated values. It offers evidence on shorter-period presentation and is determined by

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\bar{H} - \bar{H}_P)^2} \tag{19}$$

Here $\overline{H}$ are experimental values, while $\overline{H}_P$ are the predicted ones, determined from the above-mentioned empirical equations. The ideal value for RMSE is zero.

It is possible that MBE and RMSE may lead towards the poor model selection. The selection can be done by using t-statistics.

$$t - Stat = \sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}} \quad (20)$$

3. Results and Discussions. - Solar declination angle is simply an angle formed between the ray of sunlight and the equator plane of the earth. Declination angle was computed from equation 1 and the trend of varying declination angle is presented in figure 2. From where, it is obvious that solar declination angle has the highest value June and is around 23° while the minimum value of -23° will occur in the month of December. In March and September, the declination angle will become zero which means that in these two months, sun is in such position that the sun ray is parallel to the equator line.

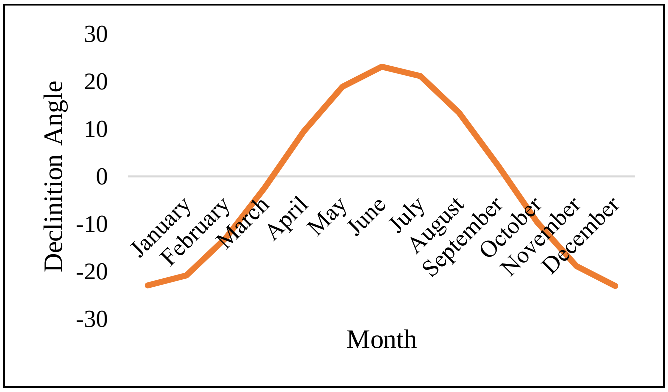

Figure II.- Declination angle variation in a year.

Extra-terrestrial radiations are those radiation which are received outside the earth surface. Extra-terrestrial radiation on horizontal surface in Karachi for the entire year was calculated from equation 2 and the variation is presented in figure 3. From figure 3, it is clear that the maximum amount of extra-terrestrial radiation will be received in the month of June and is around 11000 kWh.m^{-2}/day which means that if the atmosphere from Karachi has been evacuated then 11000 kWh.m^{-2}/day of radiation will be incident on the horizontal surface in Karachi. The minimum amount of extra-terrestrial radiation on horizontal plane will be incident in the month of December and is around 6300 kWh.m^{-2}/day. In June, generally the daylength is maximum that why maximum energy is available in the month of June while in the month of December day length is minimum due to which minimum energy is available in December.

The monthly average daily terrestrial radiations on tilted plane in the city Karachi determined from equation 11, 12, 13, 14, 16 and 18 and then compared with the experimental results. The tilt was set at 24.85° equivalent to the latitude of the city facing towards south to receive the maximum possible radiation on the inclined surface. The numbers obtained from solar models and experimental measurements are presented in figure 4. The maximum monthly average daily

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terrestrial radiation that are incident on sloped surface is around 1750 kWh.m^{-2}/day in March and October while the minimum amount of 138 kWh.m^{-2}/day is available in July because in July mostly the weather is cloudy and sunshine hours are minimum in the month of July. The variation of global radiations on tilted surface in every month is shown figure 5. From figure 5, there is slight variation in the experimental values and the estimated values.

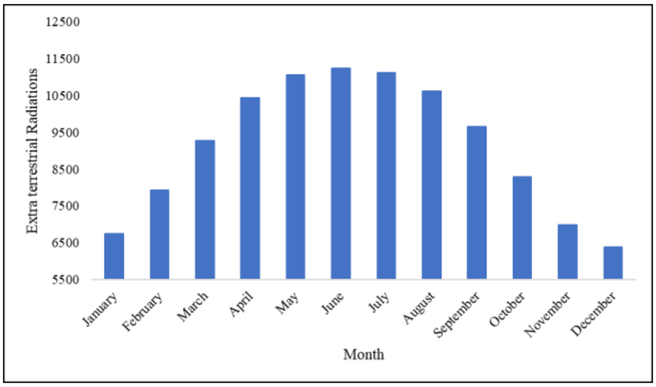

Figure III.- Variation of Horizontal radiation throughout the year.

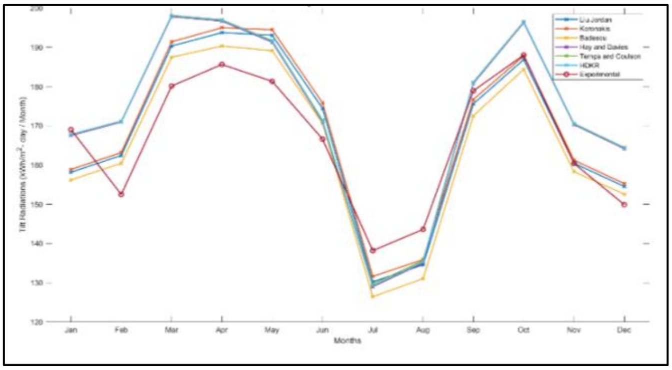

Figure IV.- Variation of total radiation on sloped throughout the year.

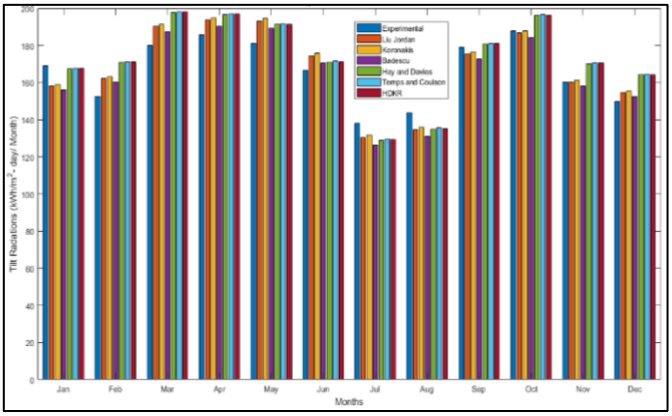

Figure V.- Month wise fluctuation of total solar energy on tilted area in Karachi.

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For extraction of the best possible model for the approximation of overall solar energy on any inclined area in Karachi, statistical techniques have been used. The estimated values have compared against the measured values. MAPE of solar models with respect to the measured value was calculated from equation 18 and is presented in figure 6. From figure 6, it is clear that Liu and Jordan model has MAPE of 4.31%, Koronakis has 4.39%, Badescue has 4.33%, Hay and Davies has 5.88%, Temps and Coulson has 5.94% while HDKR has 5.93%. On the basis of MAPE, isotropic models are considered to be more precise than the anisotropic models with lower values of MAPE.

MBE of the solar models with respect to the experimental values have been calculated from equation 19 and is presented in figure 7. From figure 7, it is clear that Liu and Jordan model has MBE of 1.69 kWh.m^{-2}per day Koronakis has 2.75 kWh.m^{-2} per day , Badescue has -1.22 kWh.m^{-2} per day Hay and Davies has 6.39 kWh.m^{-2}per day Temps and Coulson has 6.75 kWh.m^{-2}per day while HDKR has 6.58 kWh.m^{-2}per day . On the basis of MBE, isotropic models are considered to be more accurate than the anisotropic models with lower values of MBE.

RMSE of the solar models with experimental measurements have been calculated from equation 20 and is presented in figure 8. From figure 8, it is clear that Liu and Jordan model has RMSE of 7.97 kWh.m^{-2}per day , Koronakis has 8.30 kWh.m^{-2}per day , Badescue has 7.85 kWh.m^{-2}per day Hay and Davies has 10.9 kWh.m^{-2}per day Temps and Coulson has 11.04 kWh.m^{-2}per day while HDKR has 11 kWh.m^{-2}per day . On the basis of RMSE, isotropic models give more accurate results than the anisotropic models with lower values of RMSE.

As discussed, MAPE, MBE and RMSE are not the enough tool to decide the best possible model, so, t-stats were also calculated from equation 21 to select the best possible model for approximation of total radiation on the sloped surface and is presented in figure 9. It is clear that Liu and Jordan model has t-stats of 0.72, Koronakis has 1.17, Badescue has 0.52 Hay and Davies has 2.4 Temps and Coulson has 2.56 while HDKR has 2.47. On the basis of t-stats, isotropic models are considered to be more correct than the anisotropic models with lower values of t-stats. Among all the models, Badescue model is the best with lowest value of t-stats.

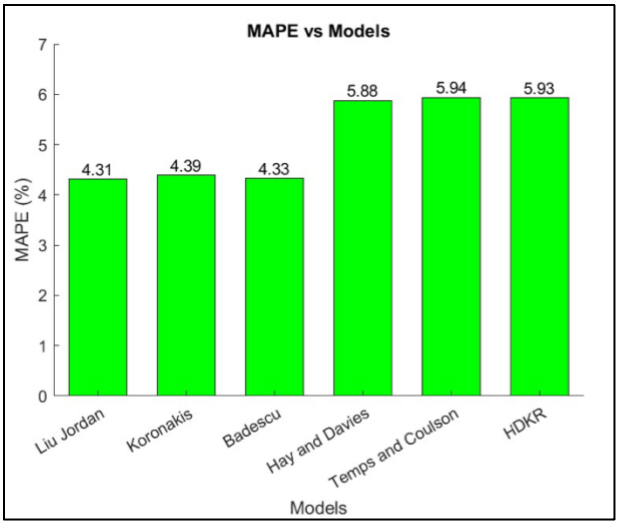

Figure VI.- MAPE of models in comparison of experimental data.

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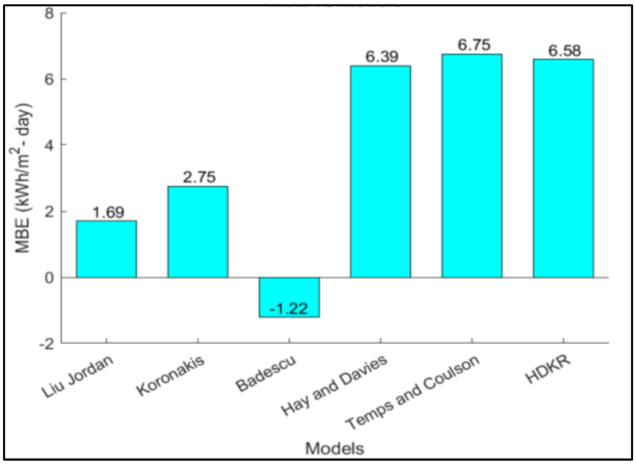

Figure VII.- MBE of models in comparison of experimental data.

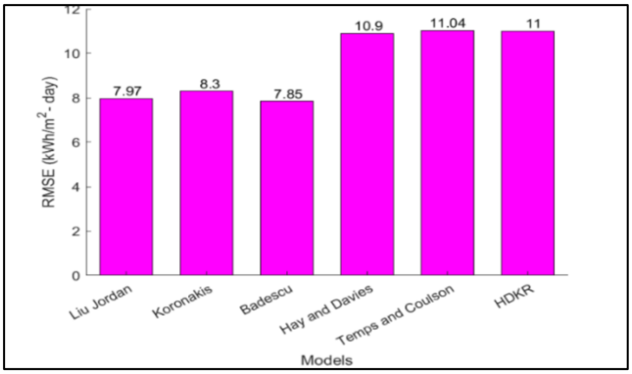

Figure VIII.- RMSE of models in comparison of experimental data.

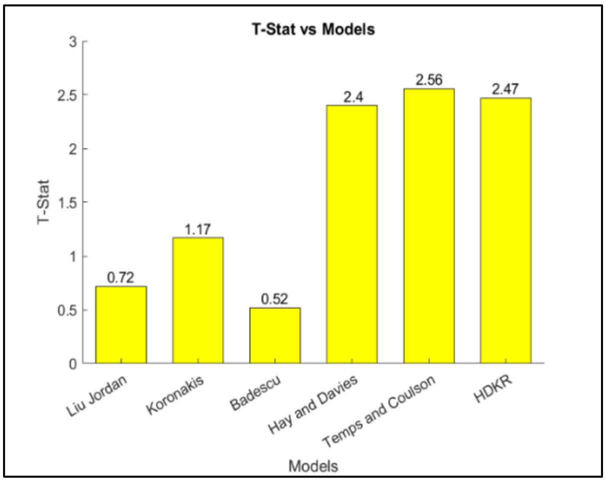

Figure IX.- t-stats of models in comparison of experimental data.

4. Conclusions. - The monthly-average daily solar energy on tilted plane in Karachi is experimentally determined and also predicted from the various solar models available. The approximated and measured data are compared by using statistical tools. Overall, isotropic models seem to be more accurate for approximation of radiation on sloped surface as compared to the anisotropic models. On the basis of MAPE, Liu and has shown the minimum deviation of -0.83% from the experimental measurements while maximum deviation was observed for Tempe and Coulson -3.86%. On the basis of MBE, Badescue model has shown the minimum error of -1.22 $kWh.m^{-2}/day$ while the maximum error is observed for Temps and Coulson with 6.75 $kWh.m^{-2}/day$. Badescue model, also shows the minimal error on the basis of RMSE with 7.85 $kWh.m^{-2}/day$ while Temps and Coulson show the maximum error of 11.04 $kWh.m^{-2}/day$. T-stats of all the models were also determined for the selection of best possible model. On the basis of t-stats, Badescue model is found to be the best model with the minimum value of 0.52 while Temps and Coulson is the utmost inappropriate model for estimation of solar radiation with the highest value of 2.56. Overall, isotropic models seem to be better models for the approximation of solar radiation on the tilted surface in Karachi with minimal errors.

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Nota contribución de los autores:

1. Concepción y diseño del estudio

2. Adquisición de datos

3. Análisis de datos

4. Discusión de los resultados

5. Redacción del manuscrito

6. Aprobación de la versión final del manuscrito

MU ha contribuido en: 1, 2, 3, 4, 5 y 6.

AAN ha contribuido en: 1, 2, 3, 4, 5 y 6.

SUHK ha contribuido en: 1, 2, 3, 4, 5 y 6.

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