ESTIMATION OF GLOBAL AND DIFFUSE SOLAR RADIATION FOR
NAWABSHAH, SINDHI, PAKISTAN

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ABSTRACT

The study of solar irradiation has been carried out for the first time over Nawabshah Sindh, Pakistan. In this study twenty two years (1983-2005) of measured data of bright sun shine hour of this region have been used to estimate global and diffuse solar radiation. Regression coefficient a and b have been calculated for the first order Angstrom type correlation for the city using relationship given by Tiwarc & Sangesta. The results obtained via four empirical models (Angstrom 1924, Liu & Jordon 1960, Page 1977, Hawas & Muneer 1980) were compared with values obtained from NASA Satellite based data (Global, diffuse). A good agreement was found between both models. The global radiation possesses larger value for the months (April –July), for the period of study. The seasonal variation in solar radiation tends to be synchronous with energy demand in Nawabshah as higher magnitude solar radiation in the summer are a major contributor to heat gain in buildings, increased air conditioning loads, and thus peak electrical demand. If solar becomes a significant portion of the energy resource mix then technologies may compensate the increasing energy demands [1].

Keywords: Direct and Diffuse Radiation, Angstrom Coefficient

1. INTRODUCTION

The radiant energy of sun is the only source of energy that influences the atmospheric motion and can be used as alternate energy resource in view of future depletion of fossil fuel reservoirs. Information about global solar radiation is important for wide variety of application, e.g. solar energy system’s design, building’s design, crop drying, photosynthesis etc. Solar radiation data is collected in major parts of world but is unavailable in developing countries like Pakistan which can not afford costly instruments [2]. So it is important to develop methods to estimate the solar radiation on the basis of available metrological data. Several formulas have been developed by various authors to estimate the amount of global solar radiation on horizontal surfaces using various parameters, such as sunshine duration, cloud cover, humidity, maximum and minimum temperatures, wind speed etc. Iqbal proposed a linear relationship in terms of clearance index for estimating monthly mean diffuse solar radiation [3]. Hepbasli and Ulgen correlated the ratio of monthly average hourly diffuse solar radiation to monthly average hourly global solar radiation with the monthly average hourly clearance index in form of polynomial relationships for the city of Izmir, Turkey [4]. Recently, Wu et al. 2007 [5] used the metrological data of Nanchang station (China) to predict daily global solar radiation from sunshine hours and dew points. Best result was achieved by model which uses sunshine duration.

Firoz Ahmed studied the prospects of solar energy utilization in Karachi without comparing to measured data [6]. In this study it is attempted to calculate Regression coefficient for the first order Angstrom type correlation as well as to estimate global and diffuse radiation for Nawabshah. The results obtained via four empirical models were compared with values obtained from NASA Satellite based data (Global, diffuse). The Nawabshah city is located at latitude 26.22 N and longitude 68.38 E. The highest temperatures each year in Pakistan, typically rising to above 48 °C, are usually recorded in Nawabshah District from May to August.

2. METHODOLOGY

The original Angstrom (1924) equation relates monthly-averaged daily irradiation H, to clear day irradiation H and the number n of hours of bright sunshine [7].

\[ H = H_0[a + b (n/N)] \]  

(1)

H, is the monthly mean daily radiation on a horizontal surface in the absence of atmosphere. N is the day length obtained by

\[ N = [2 \cos(1 - \tan \text{LAT} \tan \text{DEC} /15)] \]  

(2)

The angle between the earth-sun vector and the equatorial plane is called the declination abbreviated as DEC. Yallop’s algorithm 1992 [8] enables a high precision computation of DEC. The present routine is valid for the period 1980–2050 and has an accuracy of 1 min of arc for DEC. For longer
period high precession calculation the complete version of
VSOP theory [9] may be used. Using such algorithm DEC of
sun can be determined that leads computation of H. In order
to compute coefficients a and b, the following relationship
given by Tiwari & Sangeeta [10] can be used:

\[ a = -0.110 + 0.235 \cos \phi + 0.323 \left( \frac{n}{N} \right) \] (3)

\[ b = 1.449 - 0.553 \cos \phi - 0.694 \left( \frac{n}{N} \right) \] (4)

Where \( \phi \) is the latitude of the place and \( N \) is same above,
the values of \( H_0 \), the radiation received under the absence
of atmosphere may be calculated by [11]:

\[ H_0 = \left( 0.024 \right) \sec \left( 1 + 0.033 \cos \left( 360 \text{ DN}/365 \right) \right) \]

\[ \times \left( \cos \text{ LAT} \cos \text{ DEC} \sin W_s + \left( 2 \times \text{Ws} / 360 \right) \right) \]

\[ \sin \text{ LAT} \sin \text{ DEC} \] (5)

3. PREDICTION OF DIFFUSE SOLAR RADIATION

A regression between monthly-averaged values of diffuse
and global irradiation was first developed by Liu and
Jordan (1960) [12] in the form of \( H_g/H \) as function of \( K_2 =
H/H_0 \), where \( H_0 \) is the monthly – averaged daily diffuse
radiation incident on horizontal surface.

\[ \frac{H_g}{H} = 1.390 - 4.027KT + 5.53(KT)^2 - 3.108(KT)^3 \] (6)

Hawas and Muneer’s work was based on long term
measurement undertaken at 13 stations in india for the
period 1957-1975[13]. The model proposed by Hawas
and Muneer for the Indian sub-continent is

\[ H_d/H = 1.35 - 1.61 KT \] (7)

For temperate climates and for location close to the
tropics, the correlation equation which is widely used is
developed by Page (1977) [14] as follows,

\[ H_d/H = 1.00 - 1.13 KT \] (8)

The significance of estimating the averaged daily diffuse
radiation on a horizontal surface is that it gives a direct
measure of the energy received, say, on a horizontal solar
panel. Depending on the altitude and azimuth of the sun at
any moment if the solar panel may be adjusted accordingly
according to the solar angle increases the energy received. Such
estimates then lead to obtain estimates of the energy output
from any solar installation for energy production depending on the efficiency of the system.

4. RESULTS AND DISCUSSIONS

Table 1 gives the data of temperature and mean daily
sunshine hours for Nawabshah. The duration of “bright
sunshine” is measured through a Campbell- Stokes sunshine
recorder [15].Table 2 gives the input parameters declination

of the Sun (second column), sunshine hour’s n (third
column), and day length N (fourth column), for each month.
The day length N and Angstrom coefficients \( a \) and \( b \) were
calculated using equations 2, 3 and 4 (above) respectively.
Monthly mean daily extraterrestrial radiation \( H_e \) is estimated
from equation (5) and values are listed in table 3 (second
column). The Angstrom coefficient values are then used to
estimate monthly average daily global solar radiation \( H_g \)
using equation (1) and are given in table 3 (third column).The transparency of the atmosphere is indicated by
\( K_2 \) fraction of Extraterrestrial radiation that reaches the earth
surface as global solar radiation. It is a measure of the degree
of clearness of the sky. \( K_2 \) is calculated (fifth column) in

table 3 and the values show that sky is very clear almost
throughout the year (i.e. 69%). The ratio of the monthly
average daily diffuse radiation to the monthly average daily
global radiation \( (H_d/H) \) are calculated using equation 6, 7
and 8 from different diffuse solar radiation models. The
values for Liu & Jordan, Page and Hawas & Muneer models
are computed and given in (sixth, seventh and eighth
column) also in Table 3 respectively.

The values of Ho, Hest and HNASA are plotted over the
months as shown in figure 1.There is remarkable agreement
between the estimated and measured values for global solar
radiation as shown in figure 1. The maximum of direct
radiation for the month of June and July is quite appreciable.
The values of \( (H_d/H) \) obtained by Liu & Jordan, Page and
Hawas & Muneer models are plotted over months as shown
in figure (2). From this figure we clearly observed that The Liu
& Jordan as well as Page method predicts lower values than the
Muneer & Hawas correlation.

NASA supported satellite systems and research providing
data important to the study of climate and climate
processes. These data consists meteorological quantities
and surface solar energy fluxes [16]. These satellite and
model-based products have also been shown to be
accurate enough to provide reliable solar and
meteorological resource data over regions where surface
measurements are nonexistent, and offer two unique
features – the data is global and, in general, contiguous in
time. Typically value of the measured parameter \( H \) NASA
shown in table 3 (fourth column) is given in a tabular
format as a monthly average over the 22-year time span
Table 1: Climatological information for Nawabshah, Pakistan location of weather station: 26.3°N, 68.4°E, altitude: 38 m

<table>
<thead>
<tr>
<th></th>
<th>Data period</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean maximum</td>
<td>1983-2005</td>
<td>24.3</td>
<td>27.3</td>
<td>33.3</td>
<td>39.2</td>
<td>43.5</td>
<td>43.2</td>
<td>40.4</td>
<td>38.6</td>
<td>38.4</td>
<td>37.1</td>
<td>31.6</td>
<td>25.5</td>
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<tr>
<td>temperature (deg-c)</td>
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<tr>
<td>Mean temperature</td>
<td>1983-2005</td>
<td>15.1</td>
<td>17.8</td>
<td>23.8</td>
<td>29.5</td>
<td>34.1</td>
<td>35.5</td>
<td>34.0</td>
<td>32.5</td>
<td>31.1</td>
<td>27.7</td>
<td>21.9</td>
<td>16.4</td>
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<tr>
<td>(deg-c)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean minimum</td>
<td>1983-2005</td>
<td>5.9</td>
<td>8.7</td>
<td>14.2</td>
<td>19.7</td>
<td>24.6</td>
<td>27.7</td>
<td>27.6</td>
<td>26.3</td>
<td>23.8</td>
<td>18.2</td>
<td>12.2</td>
<td>7.4</td>
</tr>
<tr>
<td>temperature (deg-c)</td>
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<tr>
<td>Mean daily sunshine</td>
<td>1983-2005</td>
<td>8.5</td>
<td>8.9</td>
<td>8.8</td>
<td>9.2</td>
<td>10.1</td>
<td>9.4</td>
<td>8.2</td>
<td>8.5</td>
<td>9.3</td>
<td>9.7</td>
<td>9.2</td>
<td>8.5</td>
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<tr>
<td>duration (hours)</td>
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</tbody>
</table>

Table 2: Input parameters for estimation of monthly average global solar

<table>
<thead>
<tr>
<th>Months</th>
<th>Declination (in degrees)</th>
<th>Monthly mean sunshine Hour(n)</th>
<th>Monthly Average Day length(N)</th>
<th>Coefficient &quot;a&quot;</th>
<th>Coefficient &quot;b&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>-19.95</td>
<td>8.5</td>
<td>10.622</td>
<td>0.359</td>
<td>0.375</td>
</tr>
<tr>
<td>Feb</td>
<td>-10.63</td>
<td>8.9</td>
<td>11.290</td>
<td>0.355</td>
<td>0.406</td>
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<tr>
<td>Mar</td>
<td>0.15</td>
<td>8.8</td>
<td>11.99</td>
<td>0.337</td>
<td>0.444</td>
</tr>
<tr>
<td>Apr</td>
<td>11.78</td>
<td>9.2</td>
<td>12.788</td>
<td>0.333</td>
<td>0.544</td>
</tr>
<tr>
<td>May</td>
<td>20.13</td>
<td>10.2</td>
<td>13.39</td>
<td>0.346</td>
<td>0.424</td>
</tr>
<tr>
<td>June</td>
<td>23.43</td>
<td>9.4</td>
<td>13.64</td>
<td>0.323</td>
<td>0.475</td>
</tr>
<tr>
<td>July</td>
<td>20.13</td>
<td>8.2</td>
<td>13.39</td>
<td>0.298</td>
<td>0.528</td>
</tr>
<tr>
<td>Aug</td>
<td>12.18</td>
<td>8.5</td>
<td>12.81</td>
<td>0.315</td>
<td>0.492</td>
</tr>
<tr>
<td>Sep</td>
<td>0.78</td>
<td>9.3</td>
<td>12.05</td>
<td>0.349</td>
<td>0.417</td>
</tr>
<tr>
<td>Oct</td>
<td>-10.61</td>
<td>9.7</td>
<td>11.29</td>
<td>0.378</td>
<td>0.357</td>
</tr>
<tr>
<td>Nov</td>
<td>-19.86</td>
<td>9.2</td>
<td>10.62</td>
<td>0.380</td>
<td>0.352</td>
</tr>
<tr>
<td>Dec</td>
<td>-23.43</td>
<td>8.5</td>
<td>10.35</td>
<td>0.367</td>
<td>0.383</td>
</tr>
</tbody>
</table>

Table 3: Global solar radiation data

<table>
<thead>
<tr>
<th>Months</th>
<th>$H_o$ (kW h/m²)</th>
<th>$H_{sol}$ (kWh/m²)</th>
<th>$H_{NASA}$ (kWh/m²)</th>
<th>$K_T$</th>
<th>$H_r/H_0$</th>
<th>$H_r/H_l$</th>
<th>$H_r/H_{MH}$</th>
<th>$H_r/H_{Page}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>6.442</td>
<td>4.26</td>
<td>3.99</td>
<td>0.661</td>
<td>0.243</td>
<td>0.286</td>
<td>0.253</td>
<td>0.231</td>
</tr>
<tr>
<td>Feb</td>
<td>7.640</td>
<td>5.19</td>
<td>4.71</td>
<td>0.680</td>
<td>0.232</td>
<td>0.255</td>
<td>0.247</td>
<td>0.231</td>
</tr>
<tr>
<td>Mar</td>
<td>9.041</td>
<td>6.03</td>
<td>5.41</td>
<td>0.667</td>
<td>0.240</td>
<td>0.276</td>
<td>0.247</td>
<td>0.231</td>
</tr>
<tr>
<td>Apr</td>
<td>10.268</td>
<td>7.49</td>
<td>6.09</td>
<td>0.729</td>
<td>0.189</td>
<td>0.176</td>
<td>0.176</td>
<td>0.176</td>
</tr>
<tr>
<td>May</td>
<td>10.962</td>
<td>7.36</td>
<td>6.42</td>
<td>0.671</td>
<td>0.238</td>
<td>0.27</td>
<td>0.241</td>
<td>0.241</td>
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<tr>
<td>June</td>
<td>11.179</td>
<td>7.27</td>
<td>6.41</td>
<td>0.651</td>
<td>0.254</td>
<td>0.301</td>
<td>0.264</td>
<td>0.264</td>
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<tr>
<td>July</td>
<td>11.037</td>
<td>6.84</td>
<td>5.77</td>
<td>0.619</td>
<td>0.279</td>
<td>0.353</td>
<td>0.300</td>
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<tr>
<td>Aug</td>
<td>10.501</td>
<td>6.71</td>
<td>5.60</td>
<td>0.639</td>
<td>0.265</td>
<td>0.321</td>
<td>0.277</td>
<td>0.277</td>
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<tr>
<td>Sep</td>
<td>9.452</td>
<td>6.32</td>
<td>5.56</td>
<td>0.668</td>
<td>0.240</td>
<td>0.275</td>
<td>0.245</td>
<td>0.245</td>
</tr>
<tr>
<td>Oct</td>
<td>8.032</td>
<td>5.48</td>
<td>5.00</td>
<td>0.683</td>
<td>0.228</td>
<td>0.251</td>
<td>0.229</td>
<td>0.229</td>
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<tr>
<td>Nov</td>
<td>6.711</td>
<td>4.58</td>
<td>4.21</td>
<td>0.683</td>
<td>0.228</td>
<td>0.251</td>
<td>0.229</td>
<td>0.229</td>
</tr>
<tr>
<td>Dec</td>
<td>6.089</td>
<td>4.14</td>
<td>3.75</td>
<td>0.680</td>
<td>0.232</td>
<td>0.255</td>
<td>0.231</td>
<td>0.231</td>
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</tbody>
</table>
The estimated values of global and diffuse solar radiation suggest that solar radiation can be used as an alternate energy resource for this region. The result obtained shows that the solar energy utilization has bright prospects in Nawabshah, Sindh, Pakistan. The analysis of the estimated and measured values of \( H \) shows that the maximum values of global solar radiation are observed in...
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June while the minimum values appeared in December. It is further suggested that Hawaas & Munee model may be best for an estimation of monthly daily diffuse radiation over this region. A more information of the basic solar characteristics allows for the utilization of solar radiation in a broad assortment of thermal, electrical, photo biological and photochemical processes.

ACKNOWLEDGEMENT

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REFERENCES


