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Solar energy decision support system

T. V. RAMACHANDRA*†‡, RAJEEV KUMAR JHA†, S. VAMSEE KRISHNA†
and B. V. SHRUTHI†

†Energy Research Group, CES RNO 215, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India
‡Centre for Sustainable Technology, Indian Institute of Science, Bangalore, India

Energy plays a prominent role in human society. As a result of technological and industrial development, the demand for energy is rapidly increasing. Existing power sources that are mainly fossil fuel based are leaving an unacceptable legacy of waste and pollution apart from diminishing stock of fuels. Hence, the focus is now shifted to large-scale propagation of renewable energy. Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies. Solar energy is one such renewable energy. Most renewable energy comes either directly or indirectly from the sun. Estimation of solar energy potential of a region requires detailed solar radiation climatology, and it is necessary to collect extensive radiation data of high accuracy covering all climatic zones of the region. In this regard, a decision support system (DSS) would help in estimating solar energy potential considering the region's energy requirement.

This article explains the design and implementation of DSS for assessment of solar energy. The DSS with executive information systems and reporting tools helps to tap vast data resources and deliver information. The main hypothesis is that this tool can be used to form a core of practical methodology that will result in more resilient in time and can be used by decision-making bodies to assess various scenarios. It also offers means of entering, accessing, and interpreting the information for the purpose of sound decision making.

Keywords: Solar energy; Global solar radiation; DSS

1. Introduction

Renewable sources of energy offer sustainable alternatives to fossil fuels, a means of reducing harmful greenhouse emissions and opportunities to reduce our reliance on imported fuels. These resources are either inexhaustible or renewable and could satisfy most of global energy needs in the long term. Solar energy is one such renewable energy, which represent very flexible energy-supply options (Hunt 1981). The resource assessment is the basic step before considering the utilization of any energy source. With the increased interest in solar energy conservation, the need for quantitative data has assumed prime importance. Because of variability

*Corresponding author. Tel.: +91-080-3600985; Fax: +91-080-3601428; Email: energy@ces.iisc.ernet.in

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behaviour of solar energy, both on a diurnal and a seasonal scale, the accurate estimation of the resources becomes essential for its effective utilization. High-quality information on solar resources helps to implement renewable energy projects in two ways. First, by showing the overall potential for renewable energy in a country, good resource data can help renewable energy become part of the national energy development plan in areas where it makes good technical and economic sense. Secondly, reliable site-specific information is required for analysing the merits of individual projects. A lot of effort may be required to assess the quality of information and to prepare a consistent set of outputs showing accurate energy assessment. Designing a decision support system (DSS) for estimation of solar radiation energy helps to get quality information. DSS is an interactive computerized system that gathers and presents data from a wide range of data sources. It analyses and presents the collected data in a way that can be interpreted by the decision maker.

2. Solar energy

Energy generated by the sun is radiated outwards in all directions, and only two thousand-millionths of it is intercepted by the earth as light and infrared (heat) radiation. The intensity of the sun's radiation (irradiance) at the top of the earth's atmosphere at the mean distance of the earth from the sun is roughly constant (solar constant) with an observed value of $1366\,\mathrm{W/m^2} \pm 0.3\%$. However, on average, only about half of this energy reaches the earth's surface (due to scattering, absorption and reflection). The total flux of energy to a site at any given time is difficult to measure, and the flux of radiant energy alone can be measured readily at a point. However, this flux varies so widely over most land surfaces that point measurements are of limited value. The spatial heterogeneity in the radiant flux is due to the variation in solar beam irradiation caused by variation in the inclination of the earth's surface with respect to beam direction. Within a geographic region subject to uniform atmospheric conditions, irradiation from the sky is fairly uniform, regardless of surface inclination. However, the total sun and sky irradiation varies widely with surface orientation and slope. The variation of direct beam radiation varies in time with atmospheric condition and path length, the combined effect of which can be estimated (Ramachandra and Subramanian 1997).

2.1 *Characteristics of the solar radiation*

Solar radiation is made up of electro-magnetic waves (Es), which travel from the sun to the earth with the speed of light (c). Wavelength (λ) of the wave is related to the frequency (ν), and is given in equation (1)

$$c = \nu\lambda \tag{1}$$

The electro-magnetic waves of solar radiation (Es) emitted into the space and its part intercepted by the earth (Ee) is given by

$$\mathrm{Es} = 4\pi r_{\mathrm{o}}^2 I_{\mathrm{o}}\ (\mathrm{cal/min}) \tag{2}$$

$$\mathrm{Es} = 4\pi r_{\mathrm{e}}^2 I_{\mathrm{o}}\ (\mathrm{cal/min}) \tag{3}$$

where r_{o} is the mean distance between sun and earth, r_{e} the radius of the earth, and I_{o} the solar constant.

2.2 *Global solar radiation*

The quantity of short wave radiant energy emitted by the sun passing through a unit horizontal area in unit time is referred to generally as global solar radiation (G) (Mani 1980). The computation of daily sums of global solar radiation at sites where no radiation data are available can be done through various probable relationships among the climatological parameters such as from (a) sunshine and cloudiness, (b) extra terrestrial radiation (ETR) allowing for its depletion by absorption and scattering in the atmosphere. There is a relationship between solar radiation received on earth's surface and sunshine (Mani 1982).

The statistical relationship formulated between the daily duration of sunshine N and the daily total global solar radiation G is of the form

$$\frac{G}{\mathrm{G_o}} = a + (1 - a)\left(\frac{n}{N}\right) \tag{4}$$

where $\mathrm{G_o}$ is the daily global solar radiation with cloud free atmosphere, a the mean proportion of radiation received on a completely overcast day, and N the maximum possible duration of sunshine (with solar elevation $<5°$) in hours.

Owing to the difficulties in the precise evaluation of $\mathrm{G_o}$ in the aforementioned equation, $\mathrm{G_o}$ was replaced by the ETR ($\mathrm{kW\,h/m^2}$ per day) on a horizontal surface, and the relationship is given by

$$\frac{G}{\mathrm{ETR}} = a + b\left(\frac{n}{N}\right) \tag{5}$$

ETR on a horizontal surface for any place for any day/month can be estimated by the following relationship

$$\mathrm{ETR} = 10.39\, K(\cos\theta \cos\delta \sin\omega + \omega \sin\phi \sin\delta) \tag{6}$$

where 10.39 is the solar constant (assumed equal to $1.36\,\mathrm{kW/m^2} \times 24/\pi$), K the correction factor for varying earth–sun distances, ϕ the angle of latitude, δ the angle of declination, and ω the sun set hour angle in radians. Coefficient b in equation (5) expresses the rate of increase of G with increase in n/N.

To compute (n/N) at a place where only cloud cover data are available without mean sunshine data, the inverse relationship between the sunshine n/N and cloud cover C is used, which is given by

$$C = 1 - \left(\frac{n}{N}\right) \tag{7}$$

As n/N' is used for deriving G, the relation between n/N' and C is given by

$$1 - \left(\frac{n}{N'}\right) = 1C + 0.310\,C^2 + 0.476\,C^3 + 0.100\,C^4 \tag{8}$$

where N' is the maximum possible duration of sunshine (with solar elevation $>= 5°$) in hours.

Hay correlated n/N' with G'/ETR, where G' is the global solar radiation that first strikes the ground before undergoing multiple reflections. The numerical relation between G and G' is given by

$$G - G' = GR'\left[\left(0.25\frac{n}{N'}\right) + 0.60\left(1 - \frac{n}{N'}\right)\right] \tag{9}$$

where R' is the surface albedo.

The statistical relation now takes the form:

$$\frac{G'}{\text{ETR}} = a + b\left(\frac{n}{N'}\right) \tag{10}$$

Different relationships of global solar radiation are obtained by considering the influence of climatological multivariates like mean temperature T_{m}, relative humidity RH, specific humidity SH, rainfall R, and ratio of minimum and maximum temperature ψ. They are

$$\frac{G'}{\text{ETR}} = m_1 + m_2\left(\frac{n}{N'}\right) + m_3\left(\frac{n}{N'}\right)^2 \tag{11}$$

$$\frac{G'}{\text{ETR}} = c_1 + c_2\left(\frac{n}{N'}\right) + c_3 T_{\text{m}} \tag{12}$$

$$\frac{G'}{\text{ETR}} = d_1 + d_2\left(\frac{n}{N'}\right) + d_3\psi \tag{13}$$

$$\frac{G'}{\text{ETR}} = g_1 + g_2\left(\frac{n}{N'}\right) + g_3 T_{\text{m}} + g_4\text{RH} \tag{14}$$

$$\frac{G'}{\text{ETR}} = k_1 + k_2\left(\frac{n}{N'}\right) + k_3 T_{\text{m}} + k_4\text{RH} + k_5 R \tag{15}$$

$$\frac{G'}{\text{ETR}} = e_1 + e_2\left(\frac{n}{N'}\right) + e_3\psi + e_4\text{SH} \tag{16}$$

$$\frac{G'}{\text{ETR}} = f_1 + f_2\left(\frac{n}{N'}\right) + f_3 T_{\text{m}} + f_4\text{SH} \tag{17}$$

$$\frac{G'}{\text{ETR}} = h_1 + h_2\left(\frac{n}{N'}\right) + h_3 T_{\text{m}} + h_4\text{SH} + h_5 R \tag{18}$$

Specific humidity (SH) is used instead of relative humidity to take care of the relatively large variation in RH and is given by

$$\text{SH} = \text{RH}(4.7923 + 0.3647T_{\text{m}} + 0.55T_{\text{m}}^2 + 0.0003T_{\text{m}}^3) \tag{19}$$

where RH is the relative humidity.

2.3 *Diffused solar radiation*

It is the part of short wave radiation scattered by the atmosphere reflected diffusely and transmitted by clouds and passing through unit horizontal area in unit time (Mani 1980). For average conditions, diffused solar radiation (D) can be determined with reasonable accuracy from G and ETR through a linear regression equation connecting D/G on one hand and G/ETR on the other (Mani 1982). The general regression equation is of the form,

$$\frac{D}{G} = c + d\left(\frac{G}{\text{ETR}}\right) \tag{20}$$

where D is the diffused solar radiation, c the regression constant, and d the regression constant, always negative.

To secure better accuracy, D should be replaced by D' and G by G', where D' is given by

$$D' - D = G'R'\left[\left(0.25\frac{n}{N'}\right) + 0.60\left(1 - \frac{n}{N'}\right)\right] \tag{21}$$

The linear regression equation used to derive D takes the form:

$$\frac{D'}{G'} = c + d\left(\frac{G'}{\mathrm{ETR}}\right) \tag{22}$$

2.4 *Direct solar radiation*

It is the quantity of solar radiation emitted from the solid angle subtended by the visible disc of the sun and passing through a unit horizontal area in unit time (Mani 1980).

$$I_{\mathrm{H}} = G - D \tag{23}$$

Solar energy offers enormous potential for a tropical country like India. India receives solar energy equivalent to >5000 trillion kW h per year, which is far more than its total annual energy consumption. The daily average global radiation is $\sim 5\,\mathrm{kW\,h/m^2}$ per day with the sunshine hours ranging between 2300 and 3200 per year (MNES 2003).

DSS is designed on the basis of these concepts, which help in assessing the potential in a region either directly (global radiation data) or indirectly (climatological parameters).

3. Literature review

Al-Mohamad (2004) calculated the solar radiation components, namely, global, diffuse, and direct, over the Syrian landmass using several mathematical equations starting from the Angström formula. Monthly average daily global solar radiation was calculated for four locations in Syria (coastal, southern, middle, and central). An appropriate theoretical method and a computer program (developed in C++ language) were specially designed and developed for these calculations. The applicability, precision, and the accuracy of this method was statistically tested and the relative percentage error between the calculated values and the meteorological data was found to be in the range of $\pm 3\%$. It is found that the direct and the diffuse radiations constitute $\sim 70\%$ and 30% of the global solar radiation for the four chosen locations, respectively (Al-Mohamad 2004).

Teller and Azar (2001) developed TOWNSCOPE II, a computer system committed to support solar access decision-making in a sustainable urban design perspective. The software consists of a three-dimensional urban information system coupled with solar evaluation tools. Various spherical projections were developed, each of them presenting specific advantages and disadvantages for solar access visualization and/or evaluation purposes. In addition, a number of urban open space quality indicators, for instance, sky opening, were also developed so as to address the ‘multiple concern’ nature of urban design (Teller and Azar 2001).

Rylatt *et al.* (2001) developed a solar energy planning system to predict and realize the potential of solar energy on an urban scale. The system will support decisions in relation to the key solar technologies: solar water heating, photovoltaics, and passive solar gain. The system incorporates a domestic energy model and addresses the major problem of data collection in two ways. First, it provides a comprehensive set of default values derived from a new dwelling classification scheme that builds on previous research. Secondly, novel GIS tools enable key data to be extracted from digital urban maps in different operational modes (Rylatt *et al.* 2001).

Bazilian and Prasad (2002) developed a numerical model to simulate the performance of a residential-scale building integrated photovoltaic (BiPV) cogeneration system. This model was created in the Engineering Equation Solver software package (EES) from a series of highly coupled non-linear partial differential equations that are solved iteratively. The study examines the combined heat and power system in the context of heat transfer. The PV cogeneration system will be based on existing BiPV roofing technology with the addition of a modular heat recovery unit that can be used in new or renovation construction schemes. A graphical front-end has been added to the model in order to facilitate its use as a predictive tool for building professionals. It is thus a decision support tool used in identifying areas for implementation of a PV cogeneration system (Bazilian and Prasad 2002).

4. Objective

The main objective is to design and implement Solar Energy Decision Support System, which is capable of assessing solar energy potential that can be exploited to meet the regional energy demand.

5. Technical description

The DSS provides an integrated framework for easy access of data analysis and the design and evaluation of solar energy with a unified user interface, comprising of the following.

- Fully menu-driven symbolic/graphical user interface (GUI), with built-in context sensitive help features.
- The special feature of the database is its handling, display, and analysis of observation time series data, with a linkage to real-time data acquisition and monitoring.
- Computation of global solar radiation.
- It supports realistic analysis and practical simulations of solar energy assessments.

6. Methodology

The DSS for solar energy assessment (figure 1) is provided with user friendly GUI, which is developed using Microsoft Visual Basic 6.0 as front-end with MS Access database as back-end. This GUI environment helps in the process of entering data, in updating and modification of the database along with the options of computing global and diffused solar radiation and the quantification of solar energy at selected locations. Data have been collected from various climatological stations to assess solar energy. This includes the details like temperature, relative humidity, rainfall, and sunshine hours of the selected stations.

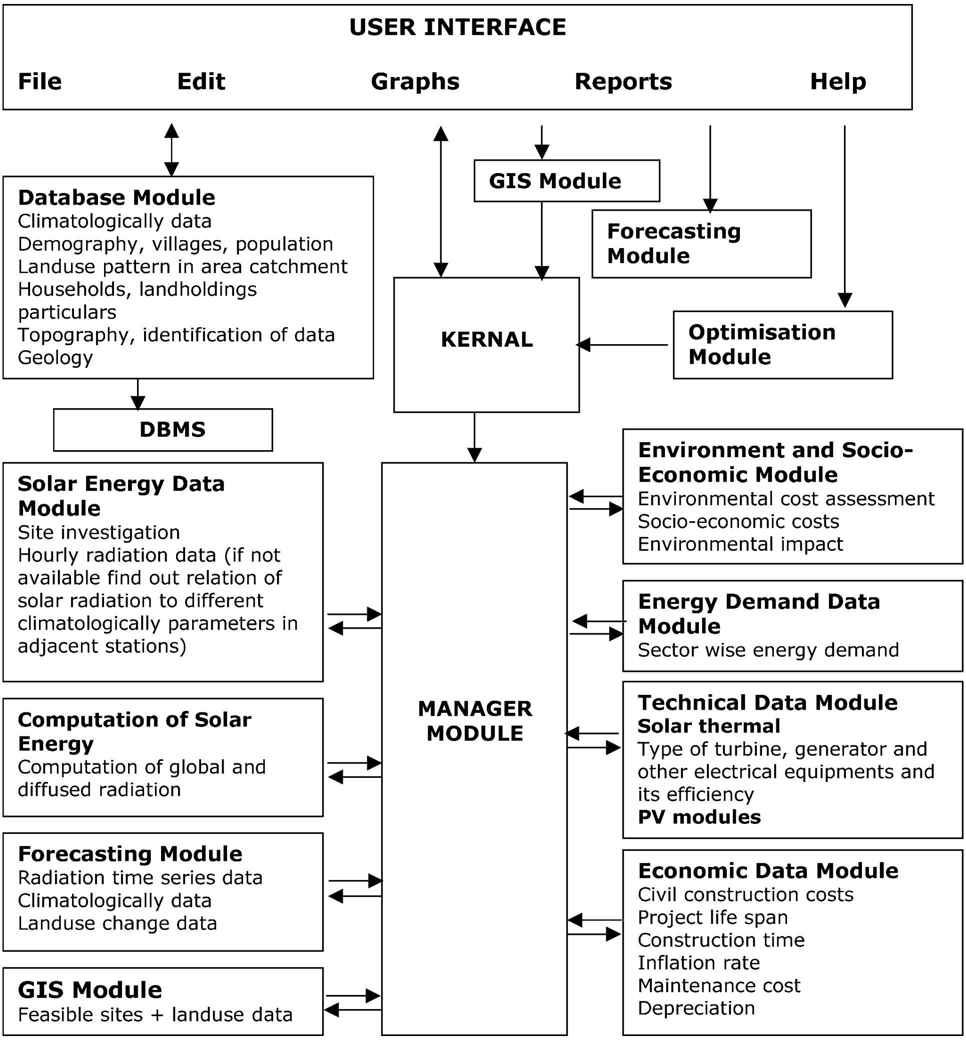


Figure 1. Design of DSS for solar energy assessment.

For districts that do not have radiation station, solar climatological data of near by stations set up by the Indian Meteorological Department were observed. Kolar district has no radiation station, so the climatological data from Bangalore station (near by station to Kolar) are observed. Radiation and climatological data were obtained from the Indian Meteorological Department.

7. Analyses, results, and discussion

7.1 *Factors influencing radiation climatology*

The quantity of solar radiation reaching the earth's surface during the day is known to be influenced by solar elevation (at noon), duration of the day as determined by astronomical and geographical factors, turbidity of the air, total amount of water vapour in the air, and amount and type of clouds. Of all these factors, solar elevation and duration of the day are important. Turbidity and amount of clouds cause relatively small variation in the quantity of solar radiation. Altitude also influences global, direct, and diffuse solar radiation received on the ground. The solar radiation climatology of any region is determined by all six of these factors, particularly the cloud type and amount. The gross solar radiation climatology follows closely the pattern of climatology of low clouds. On the basis of long-term data collected since 1963 in radiation stations, mean values of hourly global, direct, and diffuse solar radiation are computed.

The mean values of direct solar radiation were measured at 0830, 1130, 1430, and 1730 IST (Indian Standard Time) with an Angstrom pyreheliometer. The pyreheliometer observations are recorded only when the sun's disc and surrounding sky are free of clouds (Ramachandra and Subramanian 1997).

7.2 *Analyses of annual and seasonal global solar radiation*

- Annual global solar radiation: annual global solar radiation received at Bangalore is $\sim$2064.7 kW h/m^2. Progressive increase in global solar radiation takes place during January and February. During March–May, the district receives maximum radiation. A marked decrease takes place in June with the onset of the southwest monsoon.
- Sunshine: at Bangalore, the average number of hours of sunshine is $\sim$2400 h. It is evident that the duration of sunshine is longest from December to May. During this period, mostly clear sky prevails in the region. With the onset of the southwest monsoon during June–September, a significant reduction in sunshine occurs, dropping to a low of 70–80 h. From October, an increase in sunshine takes place.
- Diffuse solar radiation: the annual pattern shows diffused solar radiation of 809.90 kW h/m^2. It is seen that diffuse radiation is high between 1000 and 1600 h during May–July.

The proportion of diffuse radiation (D) to global radiation (G) varies widely, depending on the cloudiness of the sky. It is maximum during June–August and minimum (20–25%) during November–February. During November–February, D/G values undergo a characteristic diurnal variation under clear-sky conditions with minimum occurrence during noon and maximum in the morning and evening.

7.3 *Study area*

Kolar district is located in the southern plains of Karnataka state, India. It lies between 77° 21′–78° 35′ E and 12° 46′–13° 58′ N and extends over an area of 8225 km^2. The population was 25.23 lakhs in the year 2001. For administrative purposes, the District has been divided into 11 taluks. There are 15 towns and 3325 inhabited villages in the district. Kolar belongs to the semi-arid zone of Karnataka. Figure 2 shows the study area.

7.4 *Estimation of solar energy in Kolar*

Data of hours of sunshine, mean temperature, minimum and maximum daily temperature, relative humidity, and total rainfall, all as monthly averages for Kolar and Bangalore by the Indian Meteorological Department (at Pune) have been analysed and used to estimate solar radiation. Knowledge of the regression relationship between global radiation and sunshine hours at Bangalore (which agrees with observed values within 2–5%) is interpolated to determine global radiation in Kolar.

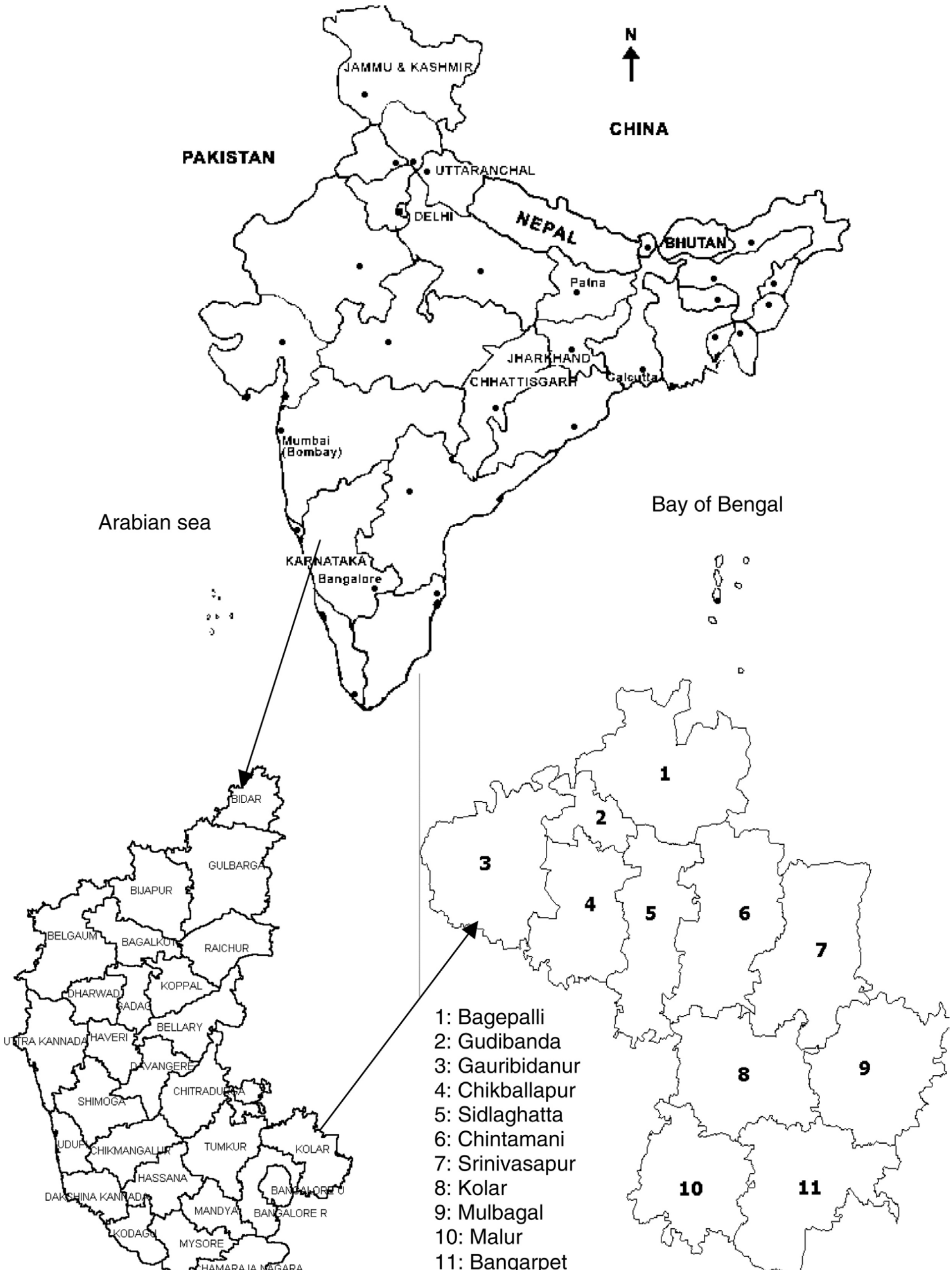


Figure 2. Study area.

7.5 *Decision support system*

The flowchart for navigating DSS is given in figure 3. An executable file is provided for this application and by executing, the login form is displayed as given in figure 4. The login option allows the existing user to enter login name and password and new users are prompted to create a new login name and password. After successful login, the solar module menu

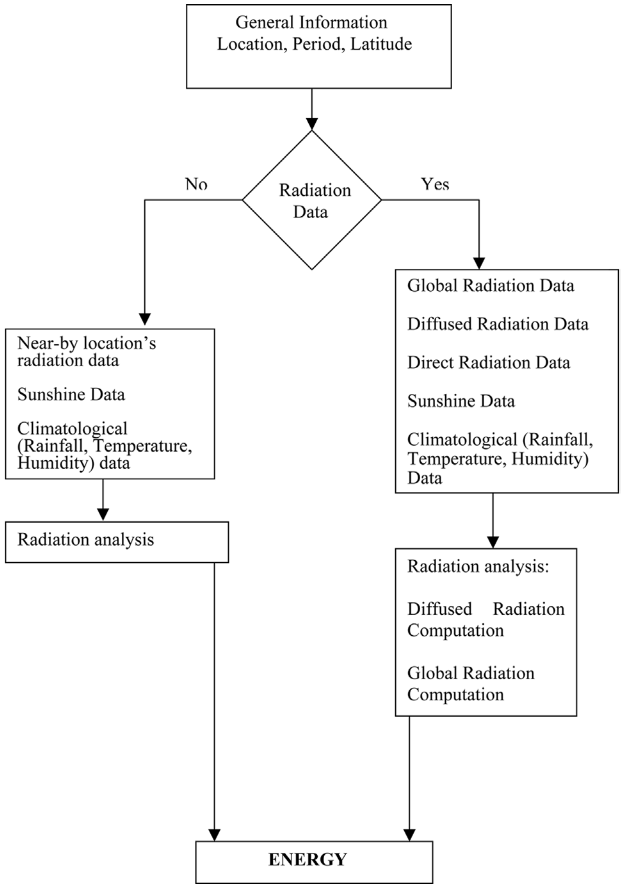


Figure 3. Navigation of DSS.

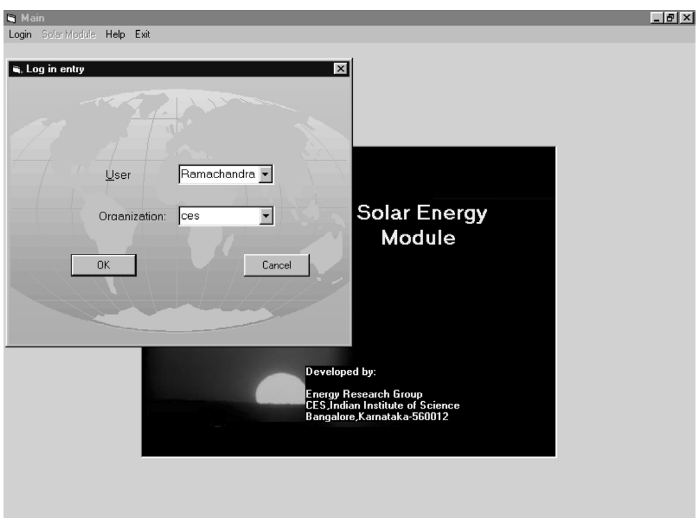


Figure 4. Login form.

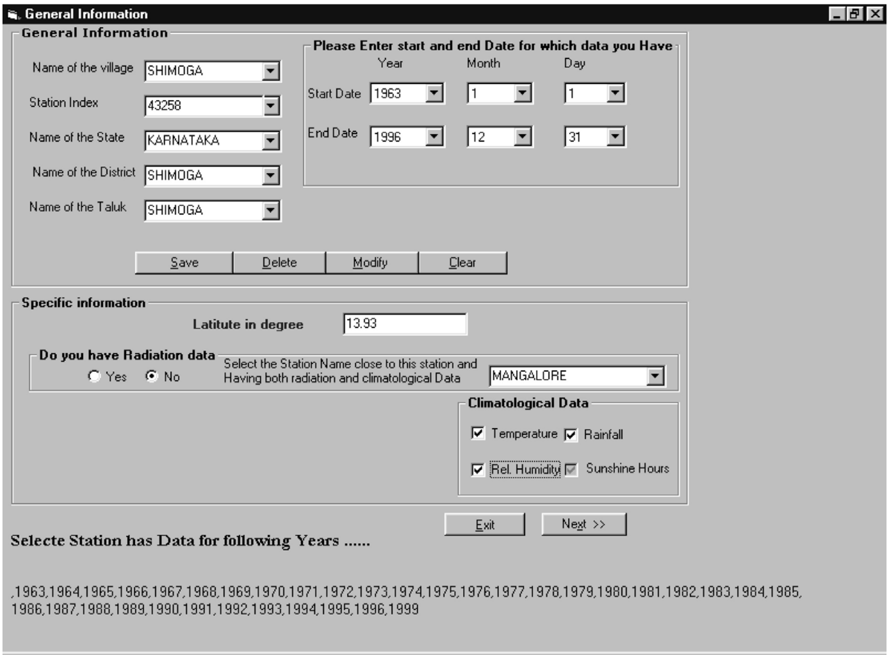


Figure 5. Climatological data entry form.

option is enabled and the user is allowed to enter details of location, period, latitude, and climatological data.

If the radiation data are not available, then a nearby station which has both radiation and climatological data is selected as shown in figure 5. Years of data available for the selected village (location) are also displayed.

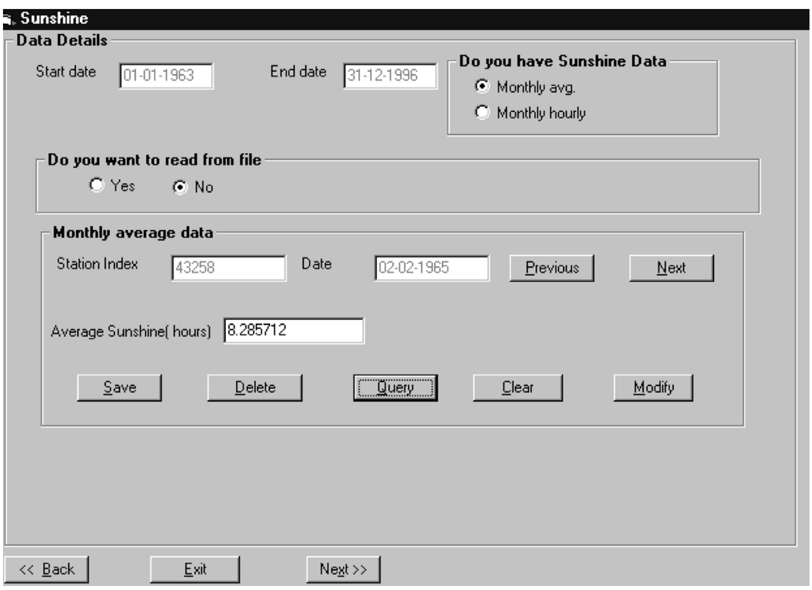


Figure 6. Sunshine data entry form.

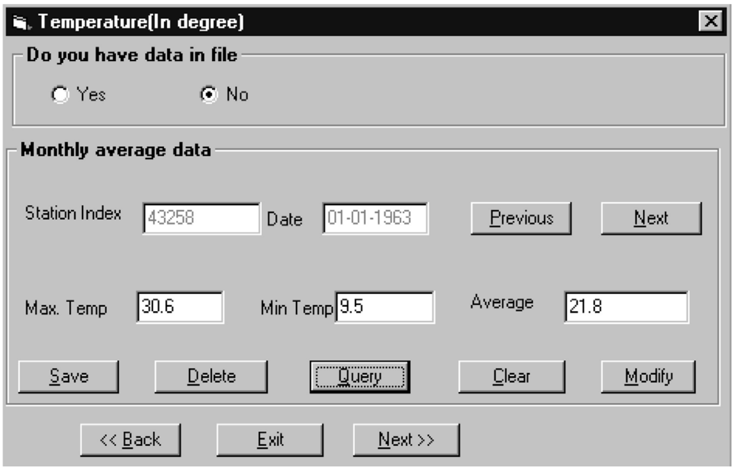


Figure 7. Temperature data entry form.

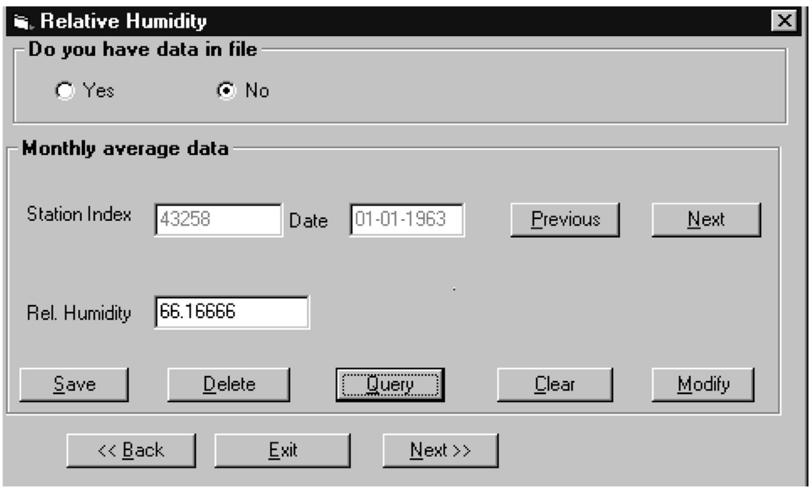


Figure 8. Relative humidity data entry form.

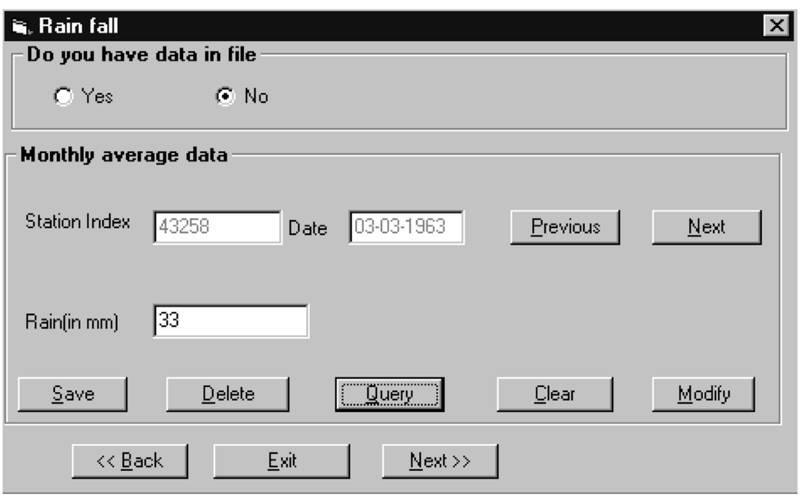


Figure 9. Rainfall data entry form.

Table 1. Monthly global radiation in Karnataka (kW h/m^2).

Station name	Station ID	January	February	March	April	May	June	July	August	September	October	November	December
Bagalkote	16205	4.80	5.55	5.95	6.36	6.14	4.49	3.79	4.32	4.71	5.05	4.70	4.48
Gulbarga	43121	4.73	5.49	5.91	6.35	6.15	4.51	3.81	4.32	4.69	5.00	4.63	4.37
Bidar	43125	4.69	5.45	5.88	6.34	6.16	4.52	3.82	4.32	4.68	4.97	4.51	4.32
Bijapur	43161	4.76	5.51	5.92	6.35	6.15	4.49	3.80	4.32	4.70	5.03	4.66	4.40
Raichur	43169	4.88	5.61	5.98	6.36	6.12	4.46	3.77	4.31	4.73	5.10	4.77	4.52
Belgaum	43197	4.84	5.58	5.96	6.36	6.13	4.47	3.78	4.31	4.72	5.08	4.73	4.48
Gadag	43201	4.86	5.59	5.97	6.36	6.13	4.47	3.78	4.31	4.73	5.09	4.75	4.50
Bellary	43205	4.87	5.61	5.98	6.36	6.12	4.46	3.77	4.31	4.73	5.10	4.78	4.52
Karwar	43225	4.95	5.67	6.02	6.37	6.10	4.44	3.75	4.31	4.75	5.15	4.84	4.60
Honnavar	43226	4.77	5.46	5.80	6.15	5.90	4.34	3.69	4.24	4.62	4.98	4.67	4.44
Shirali	43229	5.74	5.98	6.3	6.53	6.46	3.91	3.41	4.07	5.26	5.63	5.53	5.3
Chitradurga	43233	4.94	5.66	6.01	6.37	6.11	4.44	3.75	4.31	4.75	5.14	4.82	4.58
Agumbe	43257	5.39	5.98	6.12	6.41	6.07	4.01	3.43	3.92	4.92	5.05	5.12	5.13
Shimoga	43258	4.71	5.20	5.19	5.40	5.01	3.04	2.53	2.98	3.93	4.15	4.36	4.46
Balehonnur	43259	5.89	6.57	6.87	6.89	6.59	4.51	3.69	3.65	4.90	5.26	5.33	5.52
Chikmagalur	43260	5.84	6.57	6.85	6.81	6.53	4.42	3.54	3.49	4.89	5.29	5.32	5.47
Hassan	43263	5.59	6.18	6.34	6.63	6.26	4.12	3.60	4.04	5.10	5.24	5.32	5.34
Tumkur	43268	4.48	5.05	5.45	5.63	4.90	3.51	3.34	3.61	3.87	4.29	3.49	3.64
Mangalore	43284	5.53	6.08	6.12	6.37	6.02	3.83	3.18	3.97	4.53	4.99	5.07	4.97
Mercara	43287	5.29	5.84	5.94	6.20	5.83	3.85	3.32	3.78	4.75	4.90	5.01	5.04
Mandya	43289	4.25	4.72	4.99	5.56	4.87	3.48	3.32	3.31	3.68	4.14	3.63	3.43
Mysore	43291	4.62	5.16	5.53	5.82	5.13	3.79	3.69	3.73	3.89	4.32	3.68	3.71
Bangalore city	43296	5.67	6.24	6.60	6.78	6.24	4.92	4.57	4.61	4.93	5.15	4.76	4.81
Bangalore airport	43297	5.67	6.24	6.59	6.78	6.24	4.92	4.57	4.61	4.93	5.15	4.77	4.81
Kolar gold fields	43299	5.69	6.26	6.60	6.74	6.21	4.93	4.60	4.63	4.92	5.12	4.75	4.82

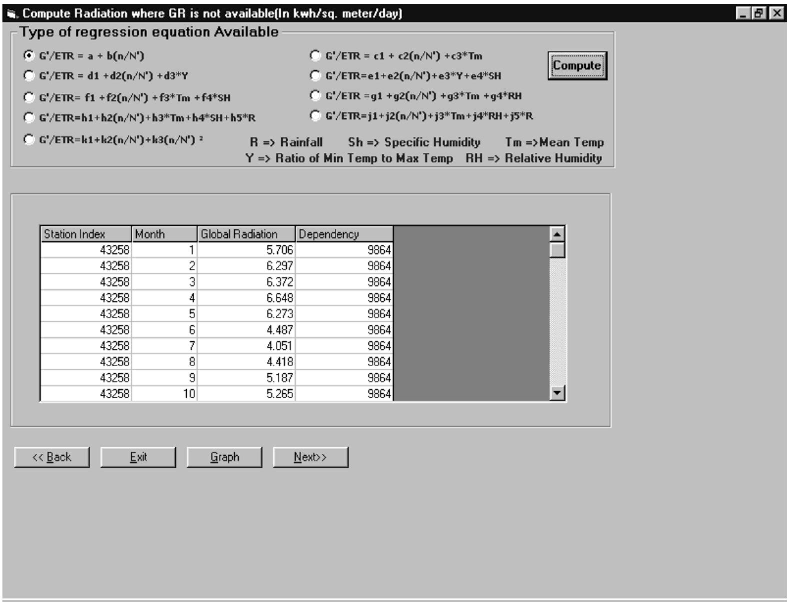


Figure 10. Regression equations to calculate global radiation.

Sunshine data can be entered or retrieved as shown in figure 6. Monthly average and monthly hours are the two options to enter data. Temperature, relative humidity, and rainfall data are entered as shown in figures 7–9, respectively.

Regression equations used to calculate global radiation are shown in figure 10. The user is allowed to select any of the available regression equation and calculated global radiation and dependency are displayed. Figure 11 shows the line graph for the computed global radiation.

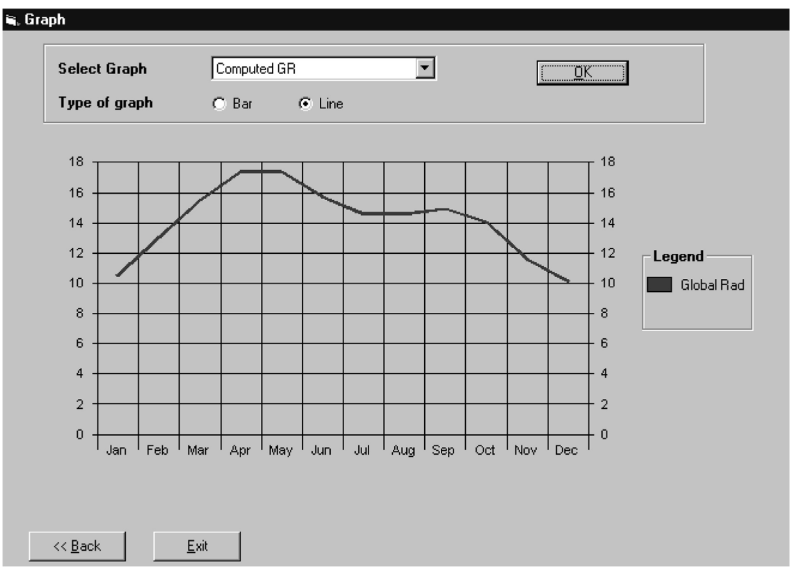


Figure 11. Computed global radiation.

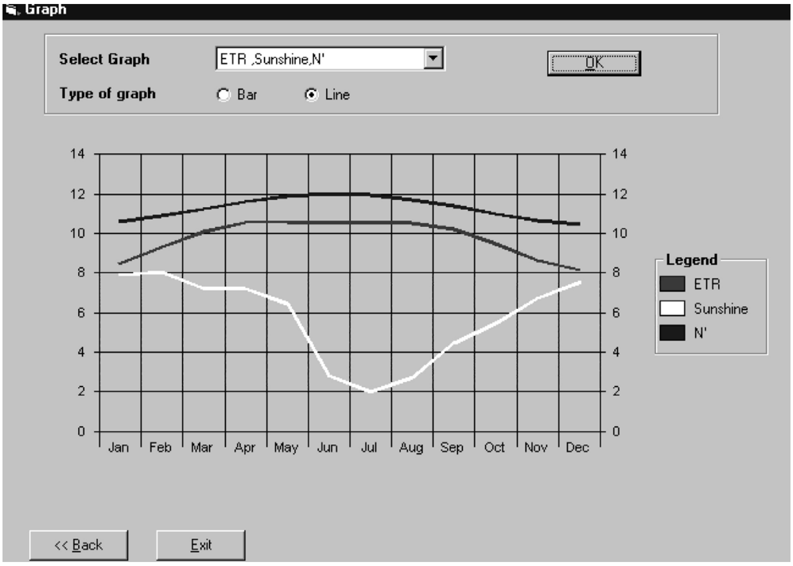


Figure 12. Computation of ETR, sunshine, and N'.

Monthly Global Radiation values (in $\mathrm{kW\,h/m^2}$) for different stations in Karnataka is given in table 1. ETR, sunshine, and N' computed are shown in figure 12.

Figure 13 shows the percentage of area used, total computed energy, energy computed with efficiency, annual energy, and actual energy. The user is allowed to select the percentage of land used, efficiency, and units.

If radiation data are available (daily/monthly/yearly), the user has to enter global radiation data, diffused radiation data, and direct radiation data. To understand diurnal variation and factors affecting variations of the solar radiation, statistical analysis of the global solar radiation was done. Figure 14 shows skewness and kurtosis analysis for monthly global solar radiation.

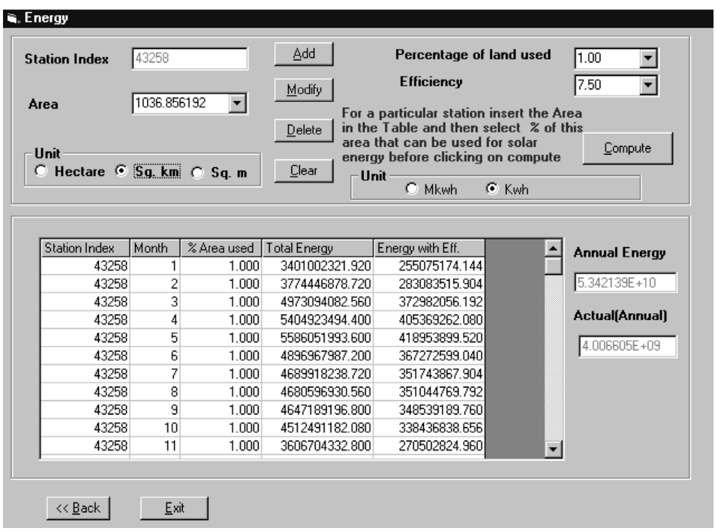
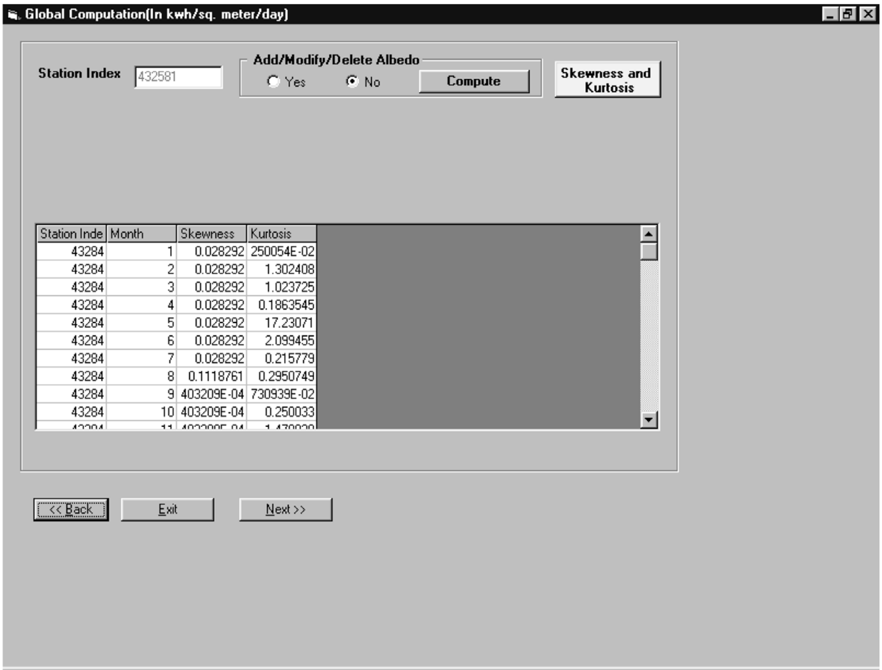
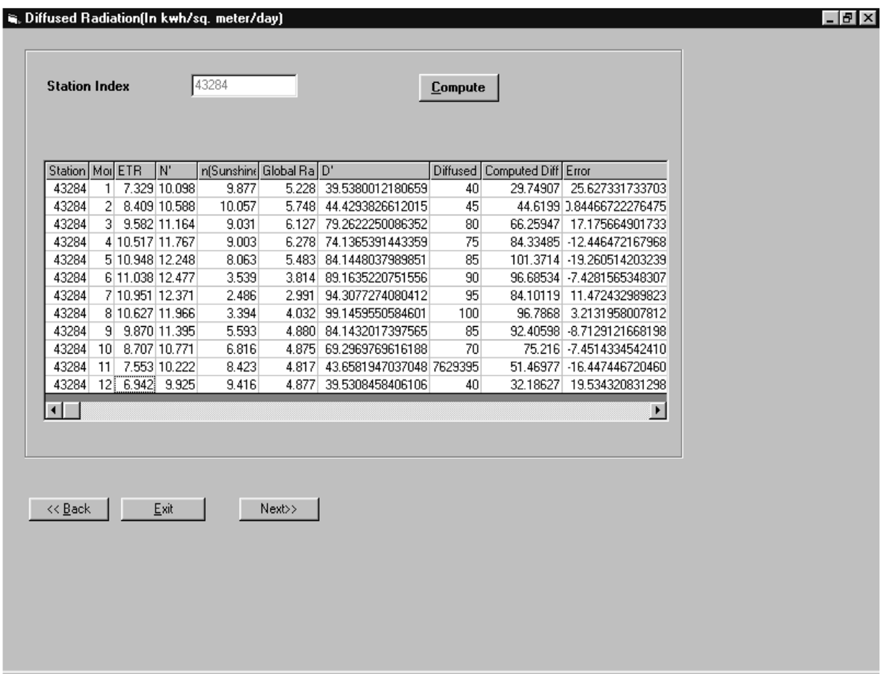


Figure 13. Percentage of area used, total computed energy, energy computed with efficiency, annual energy, and actual energy.



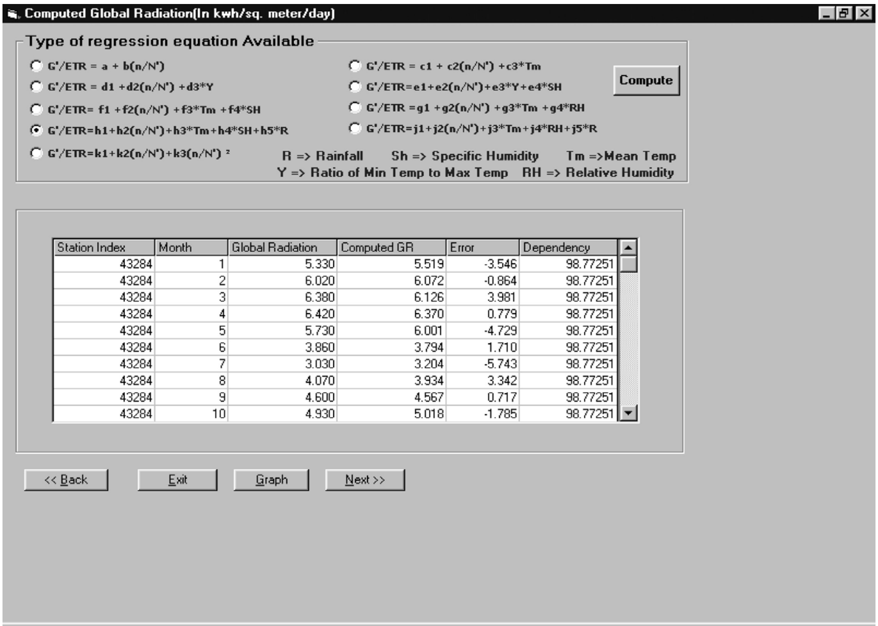
Station Inde	Month	Skewness	Kurtosis
43284	1	0.028292	250054E-02
43284	2	0.028292	1.302408
43284	3	0.028292	1.023725
43284	4	0.028292	0.1863545
43284	5	0.028292	17.23071
43284	6	0.028292	2.099455
43284	7	0.028292	0.215779
43284	8	0.1118761	0.2950749
43284	9	403209E-04	730939E-02
43284	10	403209E-04	0.250033

Figure 14. Skewness and kurtosis analysis for monthly global solar radiation.



Station	Mo	ETR	N'	n(Sunshin	Global Ra	D'	Diffused	Computed Diff	Error
43284	1	7.329	10.098	9.877	5.228	39.5380012180659	40	29.74907	25.627331733703
43284	2	8.409	10.588	10.057	5.748	44.4293826612015	45	44.6199	).84466722276475
43284	3	9.582	11.164	9.031	6.127	79.2622250086352	80	66.25947	17.175664901733
43284	4	10.517	11.767	9.003	6.278	74.1365391443359	75	84.33485	-12.446472167968
43284	5	10.948	12.248	8.063	5.483	84.1448037989851	85	101.3714	-19.260514203239
43284	6	11.038	12.477	3.539	3.814	89.1635220751556	90	96.68534	-7.4281565348307
43284	7	10.951	12.371	2.486	2.991	94.3077274080412	95	84.10119	11.472432989823
43284	8	10.627	11.966	3.394	4.032	99.1459550584601	100	96.7868	3.2131958007812
43284	9	9.870	11.395	5.593	4.880	84.1432017397565	85	92.40598	-8.7129121668198
43284	10	8.707	10.771	6.816	4.875	69.2969769616188	70	75.216	-7.4514334542410
43284	11	7.553	10.222	8.423	4.817	43.6581947037048	7629395	51.46977	-16.447446720460
43284	12	6.942	9.925	9.416	4.877	39.5308458406106	40	32.18627	19.534320831298

Figure 15. Computation of diffused radiation.



Station Index	Month	Global Radiation	Computed GR	Error	Dependency
43284	1	5.330	5.519	-3.546	98.77251
43284	2	6.020	6.072	-0.864	98.77251
43284	3	6.380	6.126	3.981	98.77251
43284	4	6.420	6.370	0.779	98.77251
43284	5	5.730	6.001	-4.729	98.77251
43284	6	3.860	3.794	1.710	98.77251
43284	7	3.030	3.204	-5.743	98.77251
43284	8	4.070	3.934	3.342	98.77251
43284	9	4.600	4.567	0.717	98.77251
43284	10	4.930	5.018	-1.785	98.77251

Figure 16. Percent error in the values of computed global solar radiation and global solar radiation.

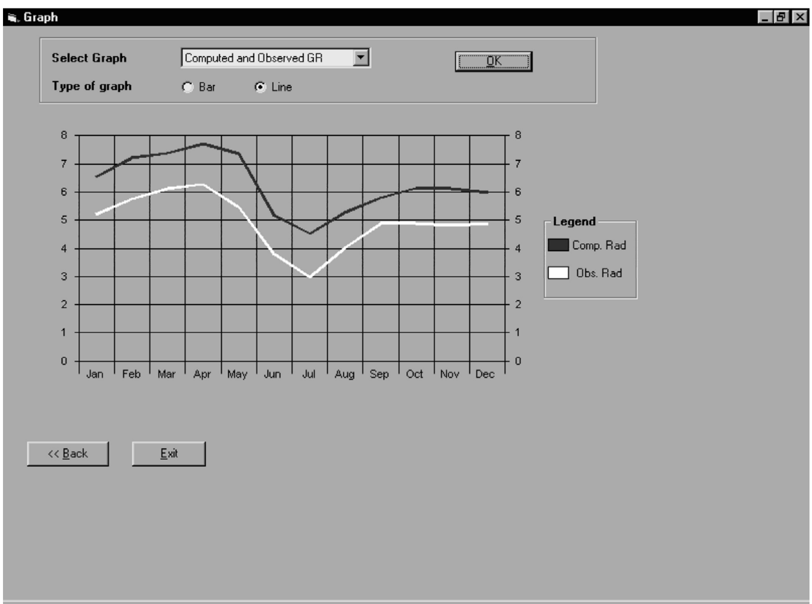


Figure 17. Graph of computed and observed global radiation.

Diffused radiation computed is shown in figure 15. Figure 16 shows the percent error in the values of computed global solar radiation and global solar radiation obtained by measurements from radiation stations. Figure 17 shows the corresponding graph of computed and observed global radiation.

8. Conclusion

As the world struggles to control energy-related greenhouse gases, electricity-starved rural families in the developing world toil to build decent lives. Solar energy can potentially play a very important role in providing most of the heating, cooling, and electricity needs of the world. With the emergence of solar photo-catalytic detoxification technology, solar energy also has the potential to solve our environmental problems. Some of the emerging developments in technology would also help in large-scale propagation. The technologies and methods used to develop and deploy DSS to aid in solar energy assessment, make work easier for a decision maker. The possibility of quickly accessing, processing, and analyses of spatial databases would offer a tremendous improvement. In spite of rapidly advancing computer technology and the proliferation of software for decision support, relatively few DSS have been developed for assessment of solar energy.

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