A New Approach For Predicting Solar Radiation In Tropical Environment Using Satellite Images – Case Study Of Malaysia

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Abstract: - Satellite images have been indentified as an alternative and accurate method for predicting average annual daily solar radiation of a specific location. These images can be use to predict the performance and sizing of various solar energy systems such as solar thermal and photovoltaic applications. The data from satellite images are used and compared with the actual readings from solar instruments. The results are then used to estimate solar intensity for other places where solar instrument is not available. Malaysia lies entirely in the equatorial region. The tropical environment has been characterized by heavy rainfall, constantly high temperature and relative humidity. The annual average daily solar irradiations for Malaysia were from 4.21 kWh/m^2 to 5.56 kWh/m^2. The highest solar radiation was estimated at 6.8 kWh/m^2 in August and November while the lowest was 0.61 kWh/m^2 in December. The Northern region and a few places in East Malaysia have the highest potential for solar energy application due to its high solar radiation throughout the year.

Keywords: - Solar radiation modeling, solar radiation mapping, satellite images, renewable energy, solar energy

1 Introduction

There has been a constant increase in energy demand to fulfill the world community need as a whole. We need energy in form of food, clothes, a place to lives and everyday necessity and uses energy for transportation, heating and many more. Most of the world communities today are still using natural resources such as petroleum and fossil fuel as their main energy resources. The main problem that may occur due to the dependent on natural resources is the decrease of these resources that will cause in market price increase. There has been a lot of study and researches done in replacing the use of fossil fuel with other renewable energy resources and one of it is the use of solar energy.

Malaysia lies entirely in the equatorial region. The climate is governed by the regime of the north-east and south-west monsoons which blows alternatively during the course of the year. The north-east monsoon blows from approximately October until March, and the south-west monsoon between May and September. The period of change between the two monsoons is being marked by heavy rainfall. The period of the south-west monsoon is a drier period for the Peninsula since it is sheltered by the landmass of Sumatra. In general, Sabah and Sarawak receive a greater amount of rainfall than the Peninsula. Hence, heavy rainfall, constantly high temperature and relative humidity characterize the Malaysian climate. Much of the precipitation occurs as thunderstorms and the normal pattern is one of heavy falls within a short period.

Generally, chances of rain falling in the afternoon or early evening are high compared with that in the morning. The country experiences more than 170 rainy days; however, an area may have a greater number of rainy days and yet receive a lesser amount of rain in a year than another area with smaller number of rainy days but receiving its rain in heavy spells. Ambient temperature remains uniformly high over the country throughout the year. Average ambient temperatures are between 26.0 to 32.0 °C. Most locations have a relative humidity of 80 – 88%, rising to nearly 90 % in the highland areas, and never falling below 60%.

Solar energy has been identified as one of the most potential alternative energy resources as Malaysia receives abundant sunshine all year long. Even though there are many solar instruments that can be used in measuring solar radiation intensity, the high cost has limited its usage to rich countries. As an alternative, a cheaper method in measuring solar intensity has been identified and this includes the use of certain parameters such as sunshine duration in Egypt by Tadros (2000) and in Vietnam by Nguyen and Pryor (1996), the use of meteorological parameters in Egypt by Trabea and Mosalam Shaltout (2000) and many more. In addition, the use of mathematical modeling and satellite images is also applicable and can be use to get information on solar radiation intensity for many places. Example includes research done by Islam and Excell (1996) on Thailand, Janjai et al. (2005) and Malik et al. (1998).

Solar radiation mapping is very important in solar energy application as it can provide information on potential area suitable for placement of solar power station (Janjai et al. 2005). Despite the importance of solar intensity information, most developing and underdeveloped countries are not well equipped with widely spread networks of pyranometers for mapping of solar radiation over large areas as the cost is very high (Islam & Exell 1996). There have been a lot of studies that use meteorological satellite data for estimation of solar radiation. Different methodologies developed for this purpose used different types of images from satellites.

In 1996, Islam and Exell have developed a low cost system called RADMAP that uses low resolution APT images transmitted from NOAA polar orbiting satellites. This system can be use to estimates solar radiation at low cost but it requires information on cloud cover and cloudy sky albedo to obtain the effective cloudiness of the sky (Islam & Exell 1996). As an alternative, this study will only use information from satellite images and data collected from several ground measuring station of solar radiation available in Malaysia. The cloud cover from satellite images are calculated and compared with the actual readings from ground measuring station. The results are then used to estimate solar intensity for other places where solar instruments are not available and finally maps that shows the solar radiation for Malaysia is developed by using GIS application.

2 Methodology

The use of satellite images in estimation of solar radiation has been developed since 1980s. For the purpose of this research, MTSAT-1R geostationary satellite images are use covering the whole of Malaysia and some neighboring countries. This grey scale satellite images are hourly taken from 7:00 am until 7:00 p.m for the period of one year starting from January until December 2006. Solar radiation data are collected from several ground measuring station of solar radiation available at Meteorological Department consist of solar radiation data from nine station which are Chuping, Alor Setar, Ipoh, Malacca, Senai, Kota Bharu, Kuala Terengganu, Kota Kinabalu and Kuching.

2.1 Estimation of cloud cover

In determining the cloud cover, the satellite images use are divided into target areas of size 50 × 50 km covering the whole of Malaysia. As the image is divided into smaller target areas, there are possibilities of having more than one type of cloud cover in a target area. In this case, a pseudo cloud is form in replace of the original cloud by taking into consideration the thickness and area of the cloud in a target area.

The thickness of clouds are determine by dividing it into five cloud types; very low, low, average, high cloud cover and very high cloud cover. This can be identified by studying the different color scale where dark color indicates low cloud cover and bright indicates high cloud cover. A grey scale from dark to bright is used to help in measuring the thickness of cloud cover. In addition, the area of cloud cover is also taken into consideration.

When T is the thickness of cloud cover, the fraction of cloud cover in a target area C can be calculated by using equation 1 where a is the area of cloud cover in a target area.

$$C = \frac{\sum T \times a}{4} \times 100 \qquad (1)$$

2.2 Estimation of solar intensity

By taking the average readings from the nine ground measuring station, comparisons are made with the percentage of cloud cover calculated from the satellite images. The solar intensity for every hour is needed as percentage of cloud cover from every hour will give different solar intensity. The solar intensity for time t can be written as:

$$I_t = i_{n90} - \left(\frac{i_{n90}}{100} \times C_t\right) \qquad (2)$$

Where I_t is the solar intensity at t hour, i_{n90} is the average 90% solar intensity from the nine ground measuring station and C_t is the cloud cover for hour t. The daily solar radiation I_{total} can be calculated by using equation 3 where t is taken from 0700 a.m. until 0700 p.m.

$$I_{total} = \sum_{t_0}^{t_n} I_t \qquad (3)$$

The monthly average daily global solar radiation I can be calculated by taking the average of daily solar radiation for each month and can be written as:

$$I = \frac{\sum_1^n I_{total}}{n} \qquad (4)$$

Where n is either 28, 29, 30 or 31 days depending on the month.

3 Results And Observations

Mapping of solar radiation gives the best initial impression on solar intensity of Malaysia for every different month including the average solar radiations receive in a year. Fig.1 shows the yearly average daily solar radiation of Malaysia. As expected, the yearly average daily solar radiation map shows that there is no significant different solar radiation intensity for both Peninsular and East Malaysia. On average, Malaysia receives about 4.96 kWh/m^2 of solar radiation in a year. The maximum solar radiation receive is 5.56 kWh/m^2 mostly in Northern region of Peninsular Malaysia and Southern region of East Malaysia. The Southern and Northeast region of Peninsular Malaysia as well as most parts in Sabah receives the lowest solar radiation. A study by Kamaruzzaman and Mohd Yusof (1992) indicate almost the same results but there is a slight increase in the minimum value from 3.375 kWh/m^2 in 1992 to 4.21 kWh/m^2 in 2006.

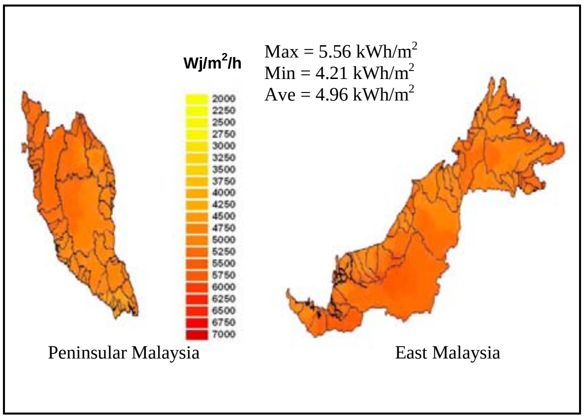

Fig.1 Annual average daily solar irradiation of Malaysia.

Fig.2 to 13 show the monthly average daily solar radiation of Malaysia for the month of January until December. From the monthly average daily solar radiation maps, a better picture of solar radiation changes for every month is shown. The Northern region of Peninsular Malaysia show the highest potential for solar energy application as this area receive the most solar radiation for almost every month including December. The minimum solar radiations receive for this area is estimated to be higher than 3.0 kWh/m^2. Apart from that, a few areas in East Malaysia also shows the potential in solar energy application as these areas receive from average to very high solar radiation especially between May until November. The lowest solar radiation estimated for East Malaysia is recorded in December until January.

In previous studies by Chuah and Lee (1984) and Kamaruzzaman and Mohd Yusof (1992), the lowest solar radiation recorded was in Northeast of Peninsular Malaysia. Quite the opposite, recent study indicates that the lowest solar radiation was receive in Southern region of Peninsular Malaysia in December. The minimum solar radiation was estimated to be at 0.61 kWh/m^2. This was supported by the recent flood tragedy in most area of Southern Region in December 2006. These changes might be an effect from the world climate change and should be monitored closely.

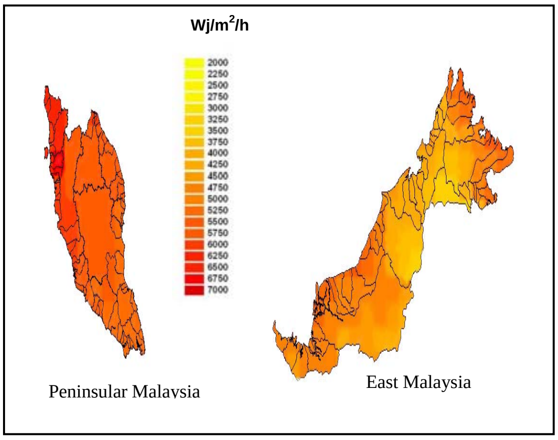

Fig.2 Monthly average daily solar irradiations of Malaysia for the month of January

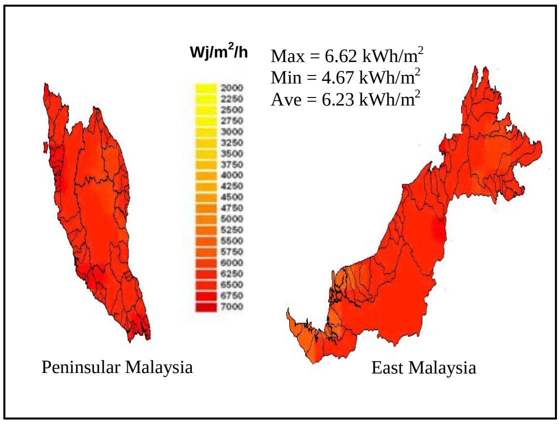

Fig.3 Monthly average daily solar irradiations of Malaysia for the month of February

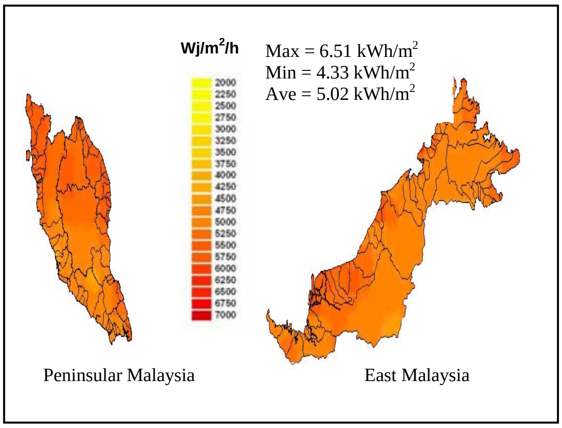

Fig.4 Monthly average daily solar irradiations of Malaysia for the month of March

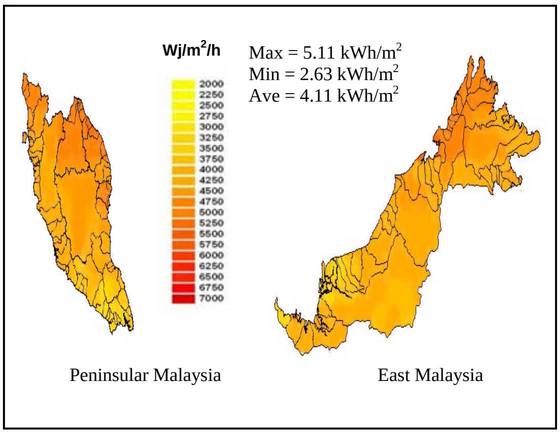

Fig. 5 Monthly average daily solar irradiations of Malaysia for the month of April.

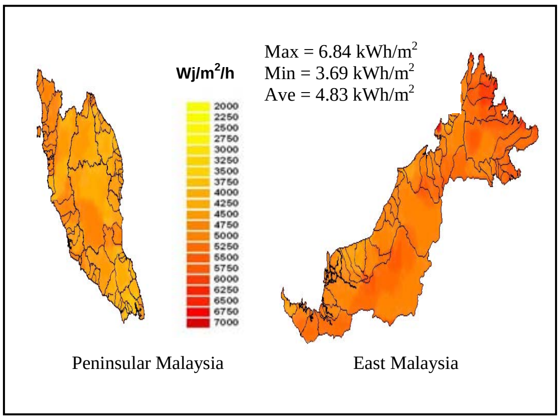

Fig.6 Monthly average daily solar irradiations of Malaysia for the month of May

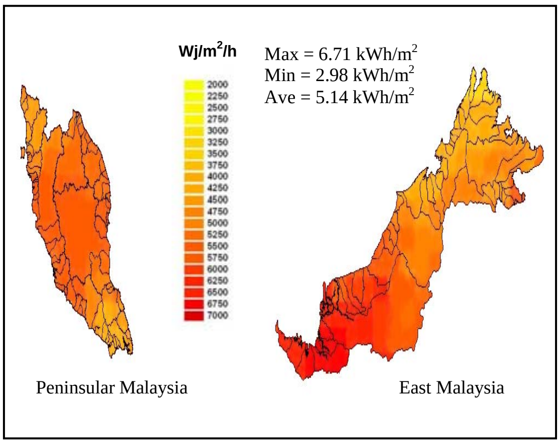

Fig.7 Monthly average daily solar irradiations of Malaysia for the month of June

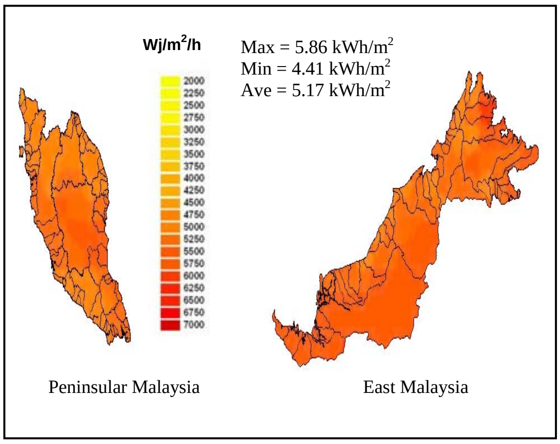

Figure 8 Monthly average daily solar irradiations of Malaysia for the month of July

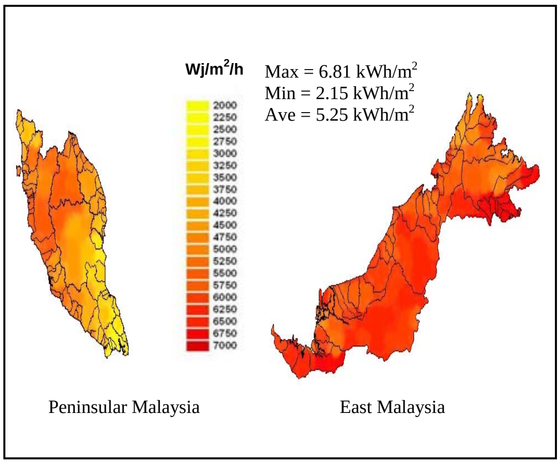

Figure 9 Monthly average daily solar irradiations of Malaysia for the month of August

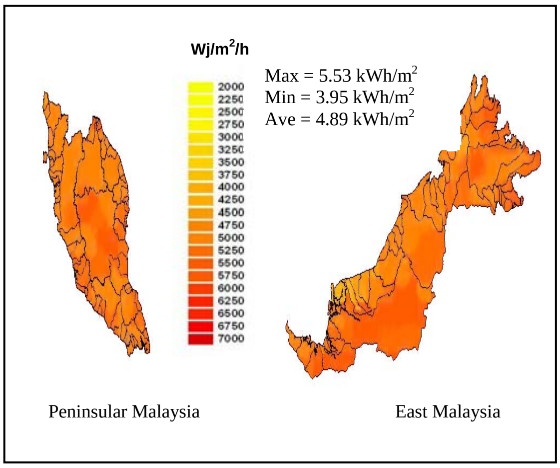

Figure 10 Monthly average daily solar irradiations of Malaysia for the month of September

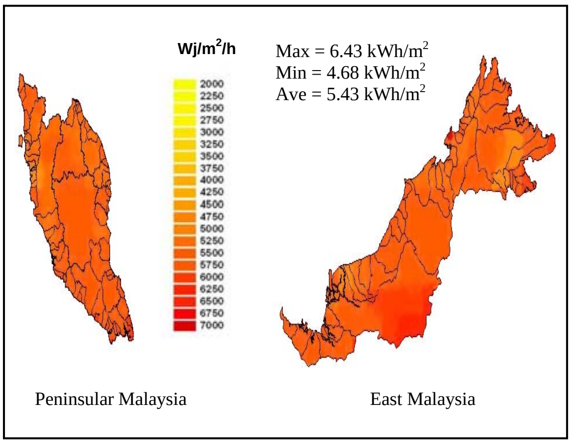

Figure 11 Monthly average daily solar irradiations of Malaysia for the month of October

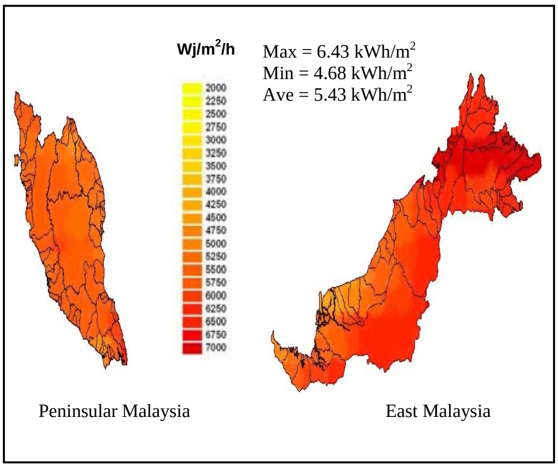

Figure 12 Monthly average daily solar irradiations of Malaysia for the month of November

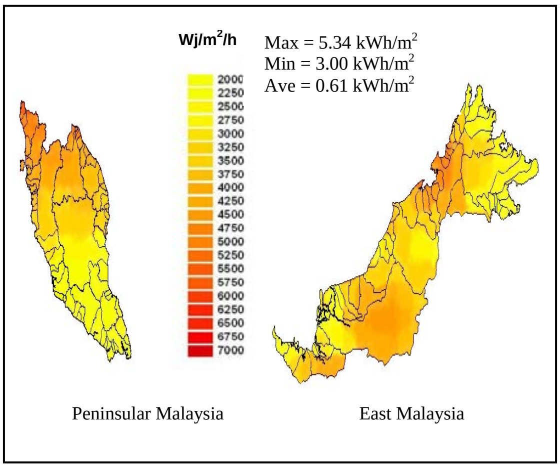

Figure 13 Monthly average daily solar irradiations of Malaysia for the month of December.

Looking at the bigger picture, there seems to be an increastment in solar radiation recorded from 1982 by Chuah and Lee to another study by Kamaruzzaman and Mohd Yusof (1992) and the recent study in 2006. The average minimum solar radiation is increasing from 3.07 kWh/m^2 in 1982 to 3.373 kWh/m^2 in 1992 and finally in 2006 the average minimum solar radiation for Malaysia is estimated to be 4.21 kWh/m^2. The increase in average minimum solar radiation indicates that the solar radiation for most places is increasing. This might be an effect from the increastment of pollution rate that leads to global warming. It is also supported by the slight increase in average solar radiation from 4.8 kWh/m^2 in 1982 to 4.965 kWh/m^2 in 2006. The average maximum solar radiation also shows a slight increast from 5.47 kWh/m^2 in 1982 to 5.572 kWh/m^2 in 1992. Apart from that, there is not much different indicates 14 years later in 2006.

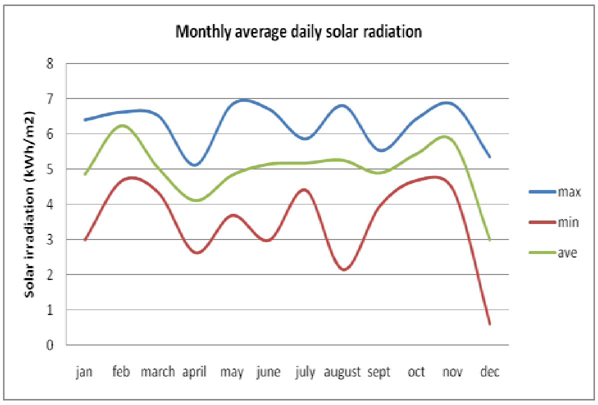

Figure 14 Maximum, minimum and average value of the monthly average daily solar irradiation for Malaysia

Figure 14 shows the graph for the Maximum, minimun and average value of the monthly average daily solar irradiation for Malaysia. This plotted graph, shows that there are three month where the maximum average daily solar radiation is almost as high as 7.0 kWh/m^2 which are in the month of May, August and November. Whereas in the month of April, July, September and December, the maximum monthly average solar radiation is lower than 6.0 kWh/m^2.

4 Conclusions

Estimation of solar radiation by using satellite images can give results at acceptable accuracy and lower cost. This method is applicable especially for developed and under developed countries in reconizing the potential of solar energy application. On average, Malaysia receives from 4.21 kWh/m^2 to 5.56 kWh/m^2 of solar radiation a year. The highest solar radiation is estimated at 6.8 kWh/m^2 in August and November while the lowest is 0.61 kWh/m^2 in December. The Northern region and a few places in East Malaysia have the highest potential for solar energy application due to its high solar radiation throughout the year.

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