GIS-Based Suitability Analysis on Hybrid Renewal Energy Site Allocation Using integrated MODIS and ASTER Satellite Imageries in Peninsular Malaysia

Conference Paper · October 2018

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GIS-Based Suitability Analysis on Hybrid Renewal Energy Site Allocation Using integrated MODIS and ASTER Satellite Imageries in Peninsular Malaysia

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ABSTRACT: This study attempts to find the most suitable place to establish hybrid renewable energy site in Malaysia where richly endowed with resources such as diverse form of biomass and solar energy. We used Satellite-derived solar irradiance estimation which is useful and accurate approach for solar resource calculation. To do so, MODIS Terra and Aqua satellite were assessed to extract values of Aerosol Optical Depth (AOD) at 550 nm. Subsequently, other topographic contribution factors were derived from ASTER satellite imagery. MODIS satellite imagery was also classified by support vector machine to extract land use/land cover. Additionally, sixteen different metrological stations were utilized to calibrate the solar irradiances achieved from MODIS satellite and provide daily wind data over the entire Peninsular Malaysia. Finally, simple additive weighting method was implemented in geographical information system platform to develop the hybrid RE suitability model. MODIS solar radiation result showed a high coloration with field observation. The result of hybrid renewable energy suitability analysis revealed that coastal areas of Hulu Terengganu, have high potential for allocating sites. This country scale research can be used as a guidance/preliminary assessment to narrow down the scope of new potential hybrid RE in regional scale.

Keywords: Hybrid renewal energy, Suitability analysis, MODIS and ASTER satellite images, geographical information system

1. INTRODUCTION

Energy is essential for today's developing universal economies. It is the centre of the global warming that is the world's main challenge. It is also consider as the main issue in the advancement of sustainable development and natural resources (Kates, 2018). The electricity manufacture from fossil fuels has great environmental effects due to air and water pollution, greenhouse gas emissions, which resulting from the burning. Emissions during the combustion process also yield residual goods that present severe health risks (Vassilev et al., 2015). Establishment of multi-purpose Renewable Energy (RE) site where solar panel and wind turbine are implemented together, is the efficient method to reduce the cost of energy distribution, site maintenance and labour force (Watson and Hudson, 2015). However, allocation of the most suitable land that has high magnitude of solar irradiance and wind power at the same time, is challenging (Tahri et al., 2015). In comparison to fossil fuels, renewable energy sources have the potential for zero or near zero emissions of greenhouse gas and other air pollutant (Panwar et al., 2011).

Suitability mapping involves using a variety of data sources in which weights are assigned to geographical criteria. Data are often imported into a Geographic Information System (GIS), which combines potentially unrelated data in a meaningful manner (Brewer et al., 2015). Weights that highlight the relative importance of one criterion to another are often determined by managers, research specialists, stakeholders, or interest groups to enhance decision-making. A variety of environmental, transportation, planning, waste management, water resources, forestry, agriculture, housing, and natural hazard applications have been undertaken using GIS multi-criteria modelling techniques (Panwar et al., 2011; Sangwan et al., 2018; Ungar et al., 2015).
Analytical hierarchy process (AHP) and simple additive weighting (SAW) are two of well-known multi criteria methods that offers flexibility, intuitive appeal to the decision makers and has ability to check inconsistencies. Decision problem is decomposed into a number of subsystems, within which and between which a substantial number of pair wise comparisons need to be completed. Some studies used multi criteria decision making (MCDM) methods for modelling

the suitability of wind farm locations. Several criteria were involved including, wind energy potential, land use, population density, distance to major roads, slope, distance to transmission lines and exclusionary areas (Miller and Li, 2014).

There are also some other studies that allocating optimal solar power plant Sites (Bartel, 2011). AHP creating a unique simple pair wise comparison of factors to weight which is deeming the top weight and the lowest factor was deemed less important than the weight factor. Decision analysis tool that enables users make a comparison of different variables. Additionally, relationships to each other structuring the outcome in a simply hierarchical way. However, there are some drawbacks that encounter in AHP method such as different opinions about the weight of each criterion, which can complicate matters. Also, it requires data based on experience, knowledge and judgment which are subjective for each decision maker.

The conducted study was divided into two parts. First section MODIS and Aster satellite image were used to retrieve solar radiation and land use. We processed open source satellite imagery to derive contributing factors in hybrid RE site selection. In second section SAW method, which implemented in GIS platform, was used to perform a hybrid RE site-suitability analysis.

2. MATERIAL AND METHOD

2.1. Study area

It is known as west Malaysia which shadowed by Thailand on the north and Singapore on the south, with South China Sea on east and Malacca Straits on the west. Its area is 130,598 km^2. Geographically it is located at latitude of 4°00' 0.00" N and longitude of 102°29' 59.99" E. Malaysia has the capability of extract the wind power and sun reflectance to electric energy. Particularly, Kuala Terengganu has the highest wind speed and considered as the best place for installing the hybrid farm. The highest solar radiance are in April and the highest wind are in February and March, and the average speed is 4.9m/s (Alkhatib, 2014).

2.2. Dataset

Aster GDEM was processed to extract the elevation layer in 30 × 30 m spatial resolution. Moderate Resolution Imaging Spectroradiometer (MODIS) products (MOD 04, 43 and 13) were analyzed to derived solar radiation, solar duration and land use/ land cover (LULC) layers with spatial resolution of 1 km and 250 m. Wind speed was extracted from 16 distributed gauging stations all over the Malaysia. Road network of Malaysia was collected from JUPEM in 1/250000 scale.

2.3. Methodology

In this study, we processed some a number of satellite imagery as well as station based data. The computational overall work flow is shown in Figure 1.

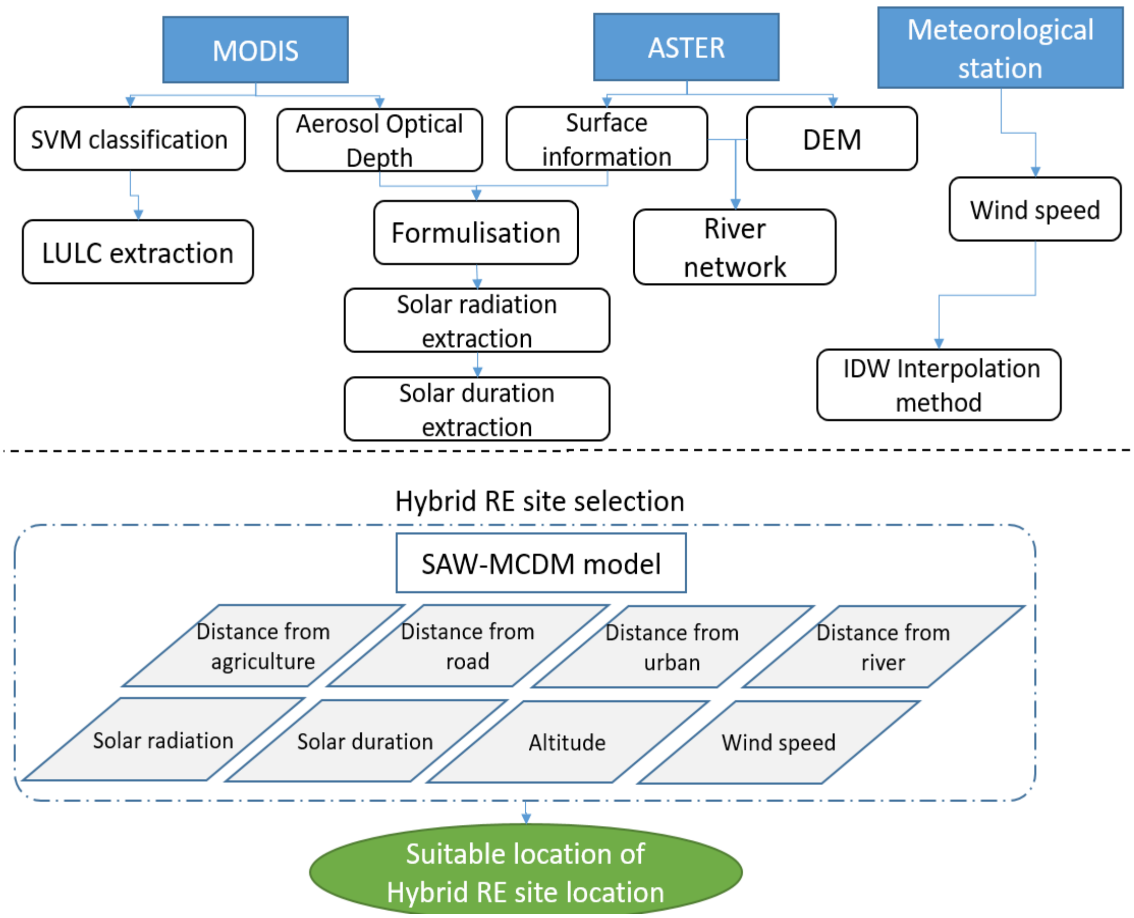


Figure 1. The overall flowchart of this study

2.3.1. Image processing: Open source MODIS data products were acquired for the first day of each month in 2017. For the present application and model testing, the MODIS data acquisition was limited to days with the availability of two overpasses; one late morning (Terra) and one afternoon (Aqua) overpass. All MODIS swath data were geo-registered using latitude and longitude geometry bands from the geolocation dataset, while the albedo product is distributed in a sinusoidal grid projection. All scenes were geometrically rectified to UTM coordinates. The geo-corrected MODIS data are provided at a sub-pixel accuracy, with a geolocation accuracy of approximately 50m at nadir (Wolfe et al., 2002). Monthly values of AOD (Aerosol Optical Depth) at 550 nm, Angstrom alpha exponent and water vapour column were taken from a gridded database that combines MODIS satellite, C005 data collection (i.e. MOD04 and 43).

2.3.2. Extraction of Solar radiation: Solar radiation $SR_{\theta,\alpha}$ with a centroid at zenith angle (θ) and azimuth angle (α) can be calculated using the Equation 1(Fu and Rich, 2002):

$$SR_{\theta,\alpha} = S_{Ct} \times \beta m(\theta) \times SD_{\theta,\alpha} \times SG_{\theta,\alpha} \times cos(AI_{\theta,\alpha}) \quad (1)$$

Where, S_{Ct} is the solar flux outside the atmosphere at the mean earth-sun distance or also called as solar constant. The solar constant that is in this analysis is 1367 W/m^2, which set as world radiation center value. β is the transmissivity of the atmosphere (averaged over all MODIS wavelengths) in the direction of the zenith. $m(\theta)$ shows the retrieved Aerosol Optical Depth (AOD) at 550 nm, from MODIS. $SD_{\theta,\alpha}$ is then the time duration represented by the sky sector that can be calculated using spherical geometry. It is basically shows the daytime interval, which is subjected to seasonal variation to the day interval (e.g. month) times to the hour interval (e.g. half an hour). $SG_{\theta,\alpha}$ reflects the gap fraction for the sun map sector. $AI_{\theta,\alpha}$ is the angle of incidence between the centroid of the sky sector and the axis normal to the surface that extracted from Aster image. $AI_{\theta,\alpha}$ between the intercepting surface and a given sky sector with a centroid at zenith angle and azimuth angle is calculated using the following equation (Rich et al., 1994):

$$AI_{\theta,\alpha} = acos(Cos(\theta) \times Cos(Gz) + Sin(\theta) \times Sin(G_z) \times Cos(\alpha - G_a)) \quad (2)$$

Where, G_a is angle of the surface zenith and G_z is angle of the surface azimuth.

2.3.3. Extraction of LULC: MODIS images have been widely used for continuous land use and land cover mapping, due to its high temporal resolution of 1-2 days despite their limited spatial resolution (Verbesselt et al. 2012; Atzberger 2013). This study employs data from the MODIS (MOD13-Q1) product captured on 2017 to extract the LULC of pansolar of Malaysia. The MODIS product used is a 16-day composite of the highest quality pixels from daily images at a spatial resolution of 250 m. Pixel-based support vector machine (SVM) classifier was used to classify the MODIS imagery into five classes including urban, agriculture, forest and water body. Then, distance analysis was applied on derived urban class to calculate the Euclidean distance from urban cells.

2.3.4. Extraction of surface information: The Aster satellite image that acquired at 2017 was downloaded from USGS open source website. Different scenes of Aster were mosaicked and georeferenced into UTM projection with 30 × 30 m resolution. Then, using hydrological tool in ArcGIS 10.6, river network was delineated. Subsequently, distance analysis was applied on derived river network to calculate the Euclidean distance to the closest source for each cell.

2.3.5. GIS suitability analysis by SAW: SAW or WLC (Weighted Linear Combination) is one of the most frequently used multi-criteria decision making (MCDA) technology (Afshari et al., 2010). It is basically based on the concept of the simple multiplication of the criteria scores with the preassigned weights. Overall scores for all alternatives are calculated and the alternative with the highest score is chosen. It has three main parts as: a) Normalize the decision matrix$(n_{i,j})$, b) Calculate the weighted normalized decision matrix(Vi,j), and Select the alternative with the highest overall performance value(A): First, the decision matrix is normalized using of linear method based on the Equation 3.

$$n_{i,j} = \frac{a_{ij}}{Max\ a_{ij}} \qquad i = 1, \dots, m, \qquad j = 1, \dots, n \qquad (3)$$

The, the weighted normalized value (Vi,j) is achieved as can be seen in Equation 4.

$$Vi,j = N_{ij}W_j \qquad i = 1, \dots, m, \qquad j = 1, \dots, n \qquad (4)$$

$$A = [A_i\ max\ \sum N_{i,j}\ W_j] \qquad (5)$$

Where W_j is the weight of the i^{th} indicator.

In order to apply SAW method in GIS platform, it is needed to take several steps. Firstly, selecting the MCDM method and related criteria, which are solar radiation, solar duration, wind speed, distance from road, distance from river, and distance from urban. Secondly, the criteria should be resampled into the same pixel size (i.e. 30 meters) and subsequently reclassification based on quintile model into 10 possible classes. Assign the proper weights into each class based on the referenced hybrid renewal energy standards. Then, perform the evaluation. Finally, overlay all layers in respect to their weightage to calculate the final map.

2.4. Accuracy assessment

Retrieved solar radiation was compared with 16 metrological stations where solar radiation was recorded daily. The average annual solar grid map then validated by achieved regression model. The LULC map also accurately assessed with 20 ground control points (GCPs) collected from Google earth imagery.

3. RESULT AND DISCUSSION

Finding the suitable place for contraction of renewal energy site is challenging. GIS and remote sensing can play a significant role to find the most suitable location for solar and wind site where has enough wind for wind turbines at the same time has enough solar radiation and duration. In this study the average annual of solar radiation was retrieved from integration of MODIS and Aster satellite images. The result was compared with metrological ground station for calibration. According to table 1, 16 stations were used to make a comprehensive comparison over the entire Malaysia. There is a high degree (R^2= 87%) of correlation between estimated solar radiations from Satellite imagery and recorded solar radiation in Station (Fig 2). Hence, the method and data were matched precisely to make the accurate solar radiation estimation.

Table 1. Recorded solar radiation in Malaysian metrological station

Station name	Estimated solar radiation from Satellite imagery (kph)	Recorded solar radiation in Station (kph)
Bandar Penggaram	4.68	4.63
Cukai	4.97	4.75
Ipoh	4.93	4.74
Kluang	4.62	4.60
Kuala Lipis	5.07	4.84
Kuala Lumpur	4.71	4.51
Kuala Terengganu	5.25	5.07
Kuantan	5.28	5.19
Kota Baharu	5.19	4.94
Melacca	4.74	4.68
Pangkal Kalong	4.92	4.77
Penang	5.03	4.96
Seremban	5.25	5.03
Sitiawan	5.14	5.10
Sungai Besar	5.05	4.86
Temerloh	4.94	4.81

Having implemented the mentioned methodology on satellite imageries, contributing criteria in RE site selection were created and mapped (Fig 3). The criteria were reclassified based on quintile method into subclasses that have unique contribution in decision regaling allocating the hybrid RE site.

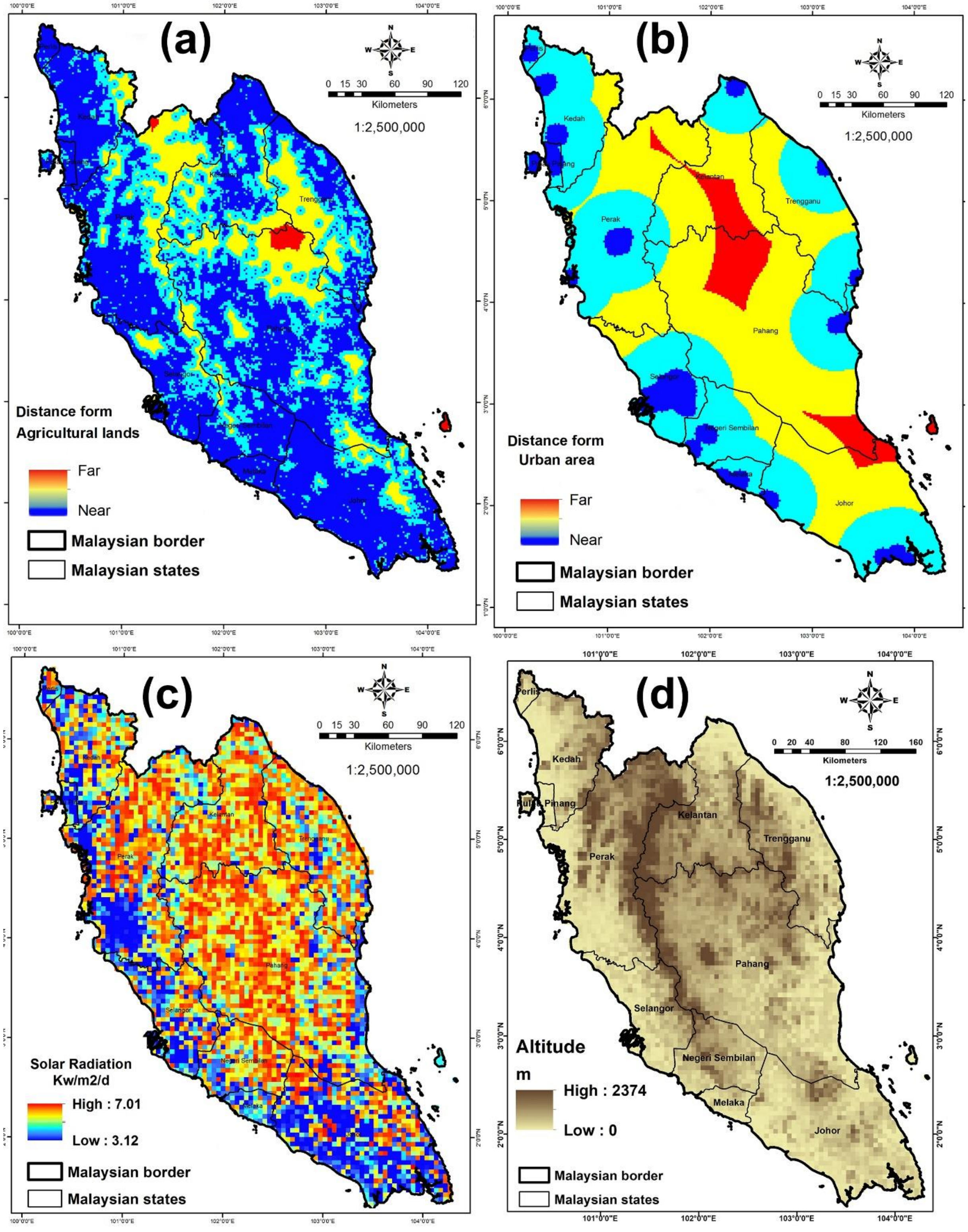
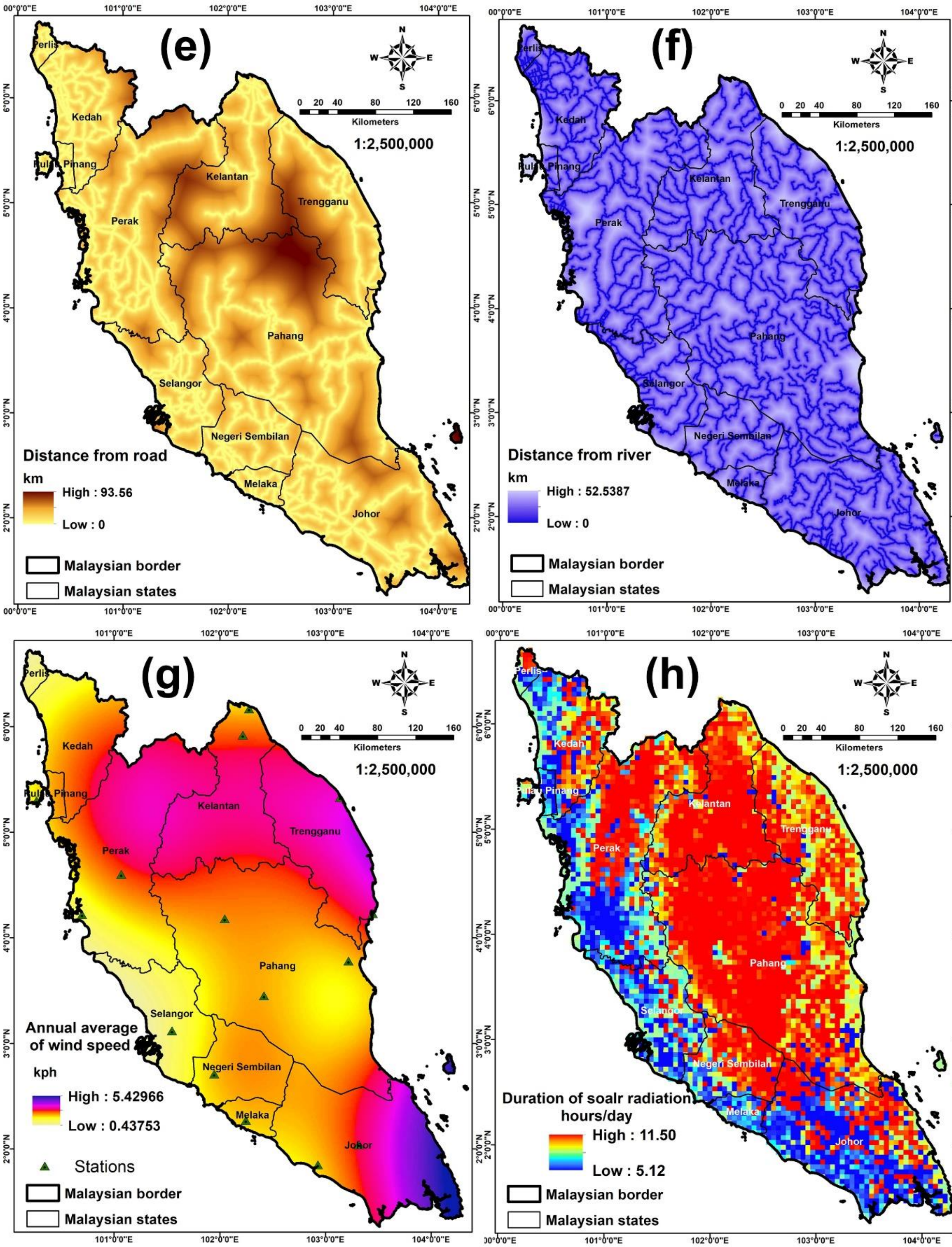


Figure 3. Visulazation of derived criteria for hybrid RE MCDM model.



Cont Figure 4. visulazation of derived criteria for hybrid RE MCDM model.

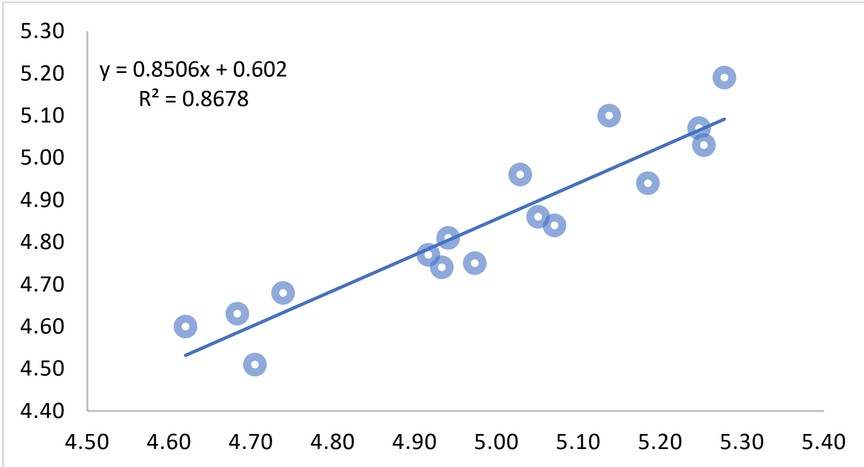


Figure 2. Regression analysis between estimated and recorded annual solar radiation

Technically speaking, in solar radiation and duration layers, the subclasses with higher value achieved higher weightage while, distance to road, agriculture and urban layers the subclasses with lower value gained the higher weightage (Table 2). Basically, the ideal site should be selected where is near to urban and agriculture to transfer the energy within a short distance. The suitable site should be near to road to have a sufficient accessibility. Additionally, it must be somewhere that have adequate amount of wind speed and at the same time high degree of solar radiation with a long day time. On the other hand, the hybrid RE needs to be constructed far from river in order to avoid any types of flooding.

Table 2. Calculated weightage for each criteria using SAW method

Subclass range		**Criteria**	**Weights**
High value	**Low value**		
significant	insignificant	Solar duration	0.1469
insignificant	significant	Distance to road	0.0752
significant	insignificant	Solar radiation	0.2800
significant	insignificant	Distance to river	0.0504
insignificant	significant	Distance to urban	0.1184
insignificant	significant	Distance to agriculture	0.1248
significant	insignificant	Altitude	0.0135
significant	insignificant	Wind speed	0.1908

After calculated the relative criteria weightage, all the criteria were overlapped with assigned weight suing spatial analysis tool in GIS environment. The final result reveal the most and least suitable area to allocate hybrid RE (Fig 4).

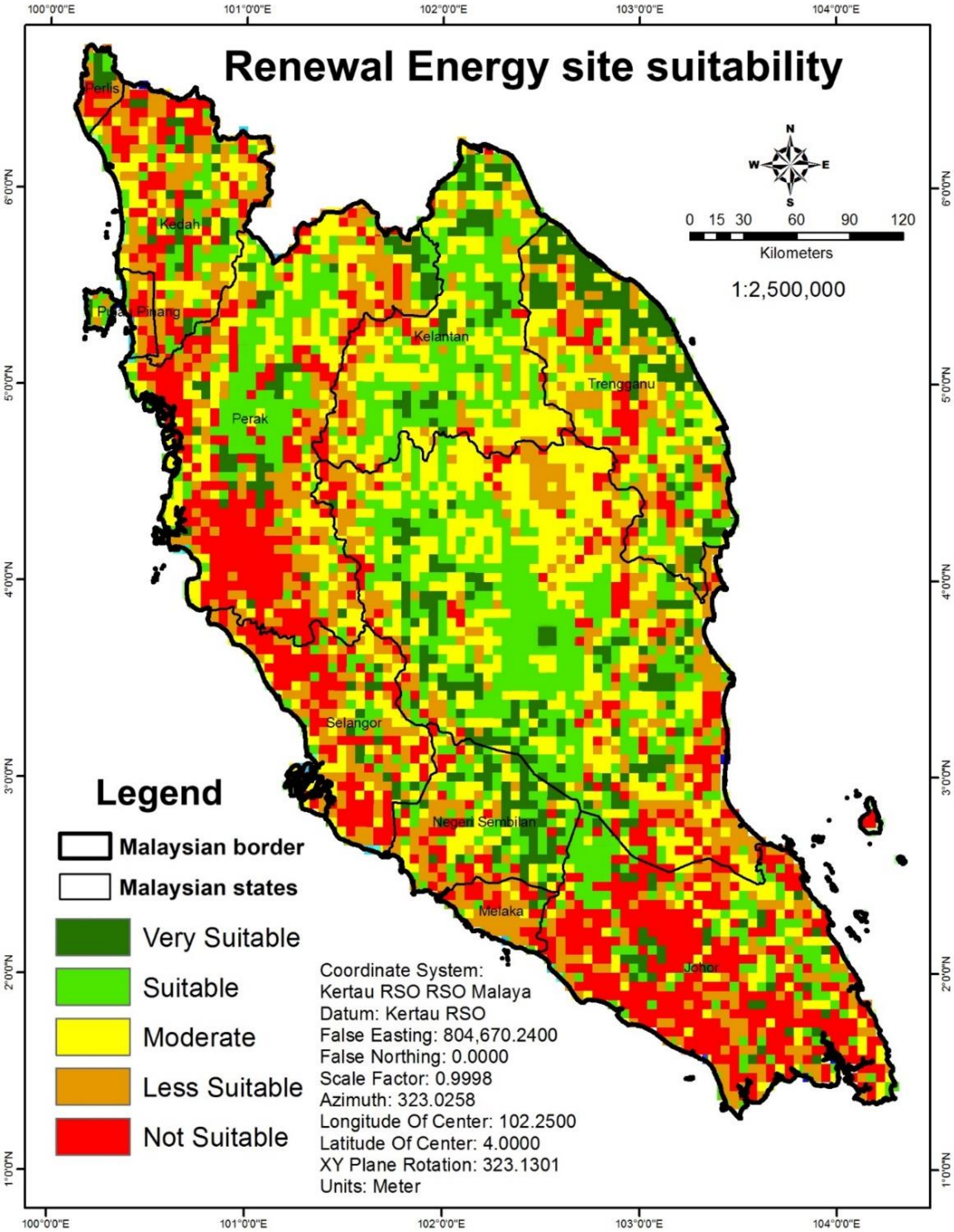


Figure 4. Selection the most suitable location for hybrid RE in Malaysia

Zones in red are unfeasible areas and zones in green colour show the RE feasible lands. The areas with high hybrid RE potential were dominantly located regions within the district of Hulu Terengganu, Terengganu and northern parts of Kelantan and Negari Sembilan.

It can be seen from figure 5 that the hybrid RE farms are highly recommended in Terengganu state where has the highest potential for hybrid farm. This result aligns with other related projects that have been implemented earlier in Malaysia (Alkhatib, 2014; Foo, 2015; Ho, 2016; Petinrin and Shaaban, 2015). Kuala Terengganu shows a significant value for wind energy (Ho, 2016). The most significant place to install wind turbine is in Pulau Layang-Layang, Sabah, Kelantan, Pahang, and Terengganu, where also have wind energy potential (Petinrin and Shaaban, 2015). The most suitable place to build the solar Farm mostly is Terengganu, where has highest potential for hybrid farm (Foo, 2015).

4. CONCLUSION

The hybrid RE is widely accepted as a major economic growth sector that can address energy security besides reducing greenhouse gas emission and mitigate climate change. Solar panel and wind turbine are primary sources of RE which have attracted the authorities' attention as a cleaner alternative to fossil fuels. Validation analysis showed that open source satellite imagery like MODIS and Aster have sufficient amount of accrue information to derive solar radiation and solar duration. Validation analysis MODIS even has a high temporal resolution to monitor the solar variation frequently. Expert knowledge in MCDM is a key part to make the best decision using SAW method. The hybrid RE sites are highly recommended to build in Terengganu state where has the highest potential for hybrid farm in terms of eight contributing criteria. However, for future works additional criteria, such as the demands of investors, utilities, governmental agencies and environmentalists can lead to much precise decision.

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