Spatial Analysis of Wind Potential for Malaysia

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Abstract- The nationwide wind resource assessment is a big challenge to all researchers in the wind energy exploitation in Malaysia. Throughout spatio-temporal analysis of wind power, regions or areas with high potential on wind energy can be easily distinguished. Thus, the aim of this study was to study the wind potential in Malaysia nationwide scale. The objectives of the study were to analyze spatial-temporal of wind potential and spatial wind power density in Malaysia. Study began with the spatial wind modeling to simulate spatial wind data or wind map. Then, spatio-temporal analysis computed the spatial wind power density from the hourly wind map. Next, spatial analysis computed the spatial distribution of the wind power density whole around Malaysia in a histogram. The total WPD for whole Malaysia was greater at higher height or altitude. Addition, there was at least 1.5232 MW of wind energy waiting for harnessing.

Keywords— Spatial analysis; Spatial-temporal analysis; Wind Potential GIS; Malaysia.

1. Introduction

Origin of utilizing renewable energy in power generation in Malaysia was the launched of Small Renewable Energy Power Programme (SREP) in 2001 [1]. Renewable energy had been added as the fifth fuel source replaced Four Fuel Diversification Policy with Five Fuel Diversification Policy under the 8th Malaysia Plan (2001–2005) [2]. Renewable energy is an umbrella term, which includes solar energy, wind energy, hydropower, biomass energy, geothermal energy, tidal power, ocean thermal energy, wave energy, and energy derived from waste, and it can be defined in several ways [3]. The renewable energy source implemented and approved by Feed-in Tariff (FiT) in Malaysia are biogas, biomass, small hydro, and solar photovoltaic [4]. Now, it is considering to include wind energy under the FiT Malaysia [5].

Wind is defined as pressure gradient that provides the impetus for the movement of air [8]. Different thermal conditions of these masses causing the air masses move [9]. Besides, wind is also referred to the atmospheric motion on a wide range scales affected by the differential heating between low and high latitudes [10]. Wind is stronger and more frequent along the shores of large lakes as well as long coast due to the differential heating between land and water [11]. The kinetic energy of wind is captured and turned into mechanical energy generating electricity by a wind turbine electrical generator [12]. In ancients, wind power had been used to work out sail boat, water pump and gain grinded, in the earliest of human history [13]. Yet, wind power used to generate electricity start developing when the first large wind machine was installed in Cleveland, Ohio, in the year 1888 [14]. Today, wind is the fastest growing renewable energy resources in the world [15-17] due to the latest technology has developed remarkable advance in wind power design [18]. Moreover, wind energy plants produce no air pollution or greenhouse gasses [19].

However, a nationwide wind resource assessment is a big challenge to all researchers in the wind energy exploitation. Development of wind system or wind farm, wind resource data, cannot be ignored. In Malaysia, majority of existing wind data were not for wind energy exploitation purpose. These wind data were provided by Malaysian Meteorological Department (MMD) for the weather forecasting and airport used. Hence, it is crucial to have a nationwide wind energy assessment study [20,21]. Spatio-temporal analysis now becomes more required in many disciplines [22,23]. Likewise, continuous spatial wind data from spatial wind modeling becomes more significant for the spatio-temporal analysis in the wind energy exploitation. Throughout spatio-temporal analysis of wind power, regions or areas with high potential on wind energy can be easily distinguished. Thus, the aim of this study was to study the wind potential in Malaysia nationwide scale. The objectives of the study were to analyze spatio-temporal of wind potential and spatial wind power density in Malaysia.

Of course, spatial analysis and spatio-temporal analysis required the spatial wind modeling simulated spatial wind data or wind map. The spatial wind data were interpolated from the point sources wind data by Kriging interpolation. Then, the spatial wind data were extrapolated to wind map at 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 m height based Digital Elevation Model (DEM) by power law extrapolation approach. Next, spatio-temporal analysis computed the spatial wind power density (WPD) from the hourly wind map which simulated by spatial wind modeling. The spatial WPD for the spatial wind modeling of height 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 m was computed to show the wind potential at different height. Spatial analysis computed the spatial distribution of the WPD whole around Malaysia in a histogram. Nine selected MMD stations' wind data were collected and used for the spatial wind modeling.

2. Methodology

2.1. Study Area and Wind Data

The wind flow patterns in Malaysia were affected the southwest monsoon, northeast monsoon and two inter-monsoon seasons [16,24]. The wind flow during the southwest monsoon is generally southwesterly and light, below 7.5 m/s [25]. Whereas, wind is steady easterly or northeasterly winds of 5 to 10 m/s during northeast monsoon season [25]. South-westerly winds may be strengthen to reach 10 m/s or more over the northwest coast of Sabah and Sarawak region during the months of April to November [25].

On bright sunny afternoons or clear nights, sea and land breezes of 5 to 7.5 m/s usually blow and reach up to several tens of kilometers inland or the coastal areas [25]. Beside, there is a daily wind occurs in many mountainous regions called mountain and valley breeze [8]. Valley breeze is the warm air rise along the mountain slope during the day time, whereas Mountain breeze is the cool air drainage into the valley after sunset [8]. Average wind speed for valley breeze is more than 9 m/s, whereas mountain breeze generally stronger than valley breeze with winds reaching speeds of 11 m/s [11].

Limited existing wind measurement in Malaysia. However, beginning of wind energy exploitation study is depended meteorological wind data, even though, the meteorological wind measurement systems were not installed for the wind energy exploitation purposes. Wind data at 9 selected stations were obtained from the MMD. There are Mersing, Kuala Terengganu, Pulau Langkawi, Sandakan, Kudat, Kota Kinabalu, Bintulu, Kuching and Tawau. These nine selected interpolation points represents the wind speed at the coast or flat areas in Malaysia. The locations of the 9 selected MMD monitoring stations were shown in Figure 1.

Figure 1. Location map of selected meteorological stations.

Each MMD station there consist of a wind mast which have installed wind sensors (wind vanes and anemometer) at 10 m height to obtain wind data. Wind vanes are respond to the change in wind direction when the wind speed is more than 1 m/s [25]. Degrees of wind direction were measured clockwise from the geographical north and showed the direction from which the wind is blowing [25]. Meanwhile, anemometer is the cups mounted symmetrically at right angle to a vertical shaft and measured the wind speed in m/s [25]. Wind is consider calm when wind speed is less than 0.5 m/s [25].

In order to obtain a reliable yearly average of wind speed, five years data recording was needed [26,27], but one year wind data would be only sufficient enough to realize its potential [16]. The one year wind data only showed the initial wind characteristics and spatial simulated wind potential, so varying wind speed from year to year had been neglected.

2.2. Spatial Wind Modeling

Hourly wind data obtained from 9 selected MMD's stations were interpolated to hourly spatial wind data by Kriging interpolation. The most common and basic technique for Kriging interpolation is Ordinary kriging [23,28-30].

Ordinary Kriging assumes that there is no constant, mean for the data over an area mean (i.e., no trend) [23,28,29]. Ordinary Kriging weights come from a semivariogram [29]. In this study, spherical model was selected for the spatial interpolation of wind data due to it is one of the common semivariogram model for Ordinary Kriging.

Next, the hourly spatial wind data were extrapolated to wind map at 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 m by the power law equation[31-33]:

$$v = v_0\left(\frac{z}{z_0}\right)^{\alpha} \quad (1)$$

where in this study, v is wind map at desired height; z is the DEM which carrying the desired altitude values; v_0 is spatial wind data established Kriging interpolation; z_0 is the measured height of the MMD stations which is 10 m; α is can be set to a general constant value, 0.143. Figure 2 shown the summary of the spatial wind modeling in this section.

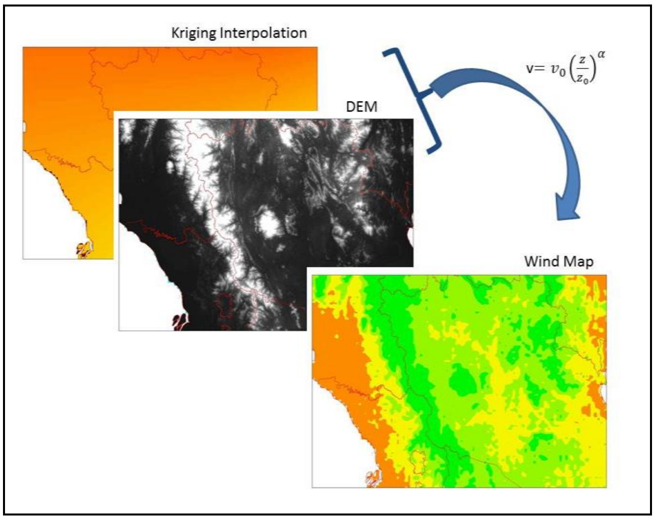


Figure 2. Spatial wind modeling.

DEM which carrying the desired altitude values was depicted by adding the desired values 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 m to the DEM which carrying the elevation values. The rationale of adding desired values to DEM was because of depiction of a wind map to represent the spatial wind speed at the desired height above the ground. Besides, the extrapolation was based on 10 m MMD measured height, z_0. Therefore, it was required to add the desired values to the DEM to avoid the negative values obtained for the wind map.

2.3. Spatial-Temporal and Spatial Analysis

Previous section, spatial wind modeling, were established continuous spatial wind data which were hourly wind maps at 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 m height. Through spatio-temporal analyses, spatial wind power density (WPD) were computed from the hourly wind map at different height. Spatial WPD was computed by the following equation [34,35]:

$$WPD = \frac{1}{2n}\sum_{i=1}^{n} \rho v_i^3 \quad (2)$$

where, n is the number of hours in a year, 8760; ρ is the density of air at standard conditions (sea level, 15°C), 1.225 kg/m^3; v_i^3 is the cube of the ith hourly wind maps at different height. The units for WPD is W/m^2 and defined as the wind power available per unit area swept by the turbine blades [31,34-36]. Figure 3 shown the summary of the spatial WPD computation in this section.

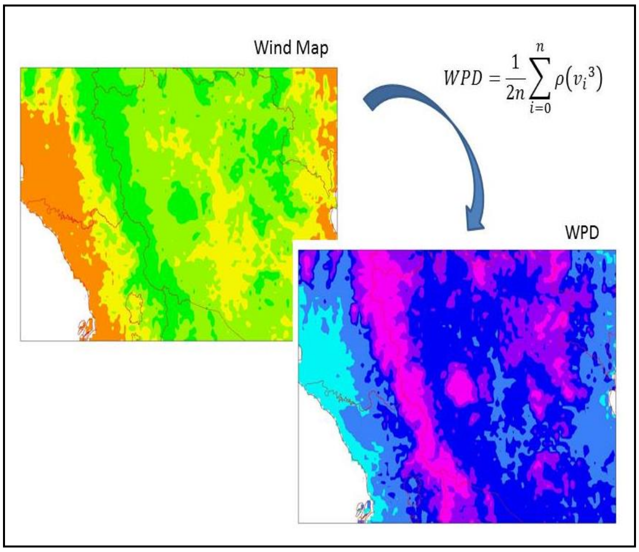


Figure 3. Spatial Wind Power Density Computation.

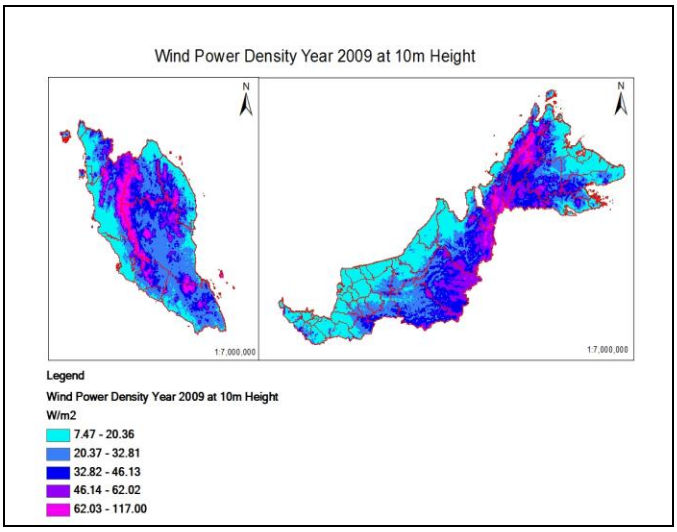
Next, spatial analysis computed the frequency distribution of the WPD for whole Malaysia in a histogram. Spatial WPD for Malaysia was divided into a total of 38845 raster or pixel or areas and each raster carried the value of WPD. Then, the frequency distribution of the WPD for whole Malaysia for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 m height were plotted as histogram.

3. Results and Discussion

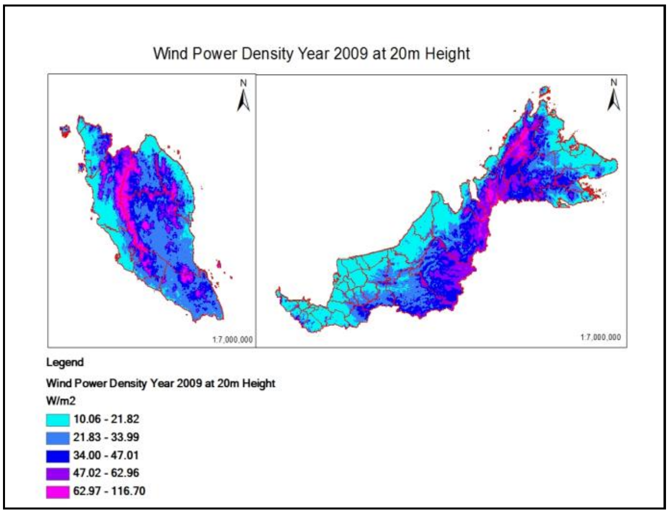
3.1. Spatial Wind Power Density

Figure 4(a-j) show the spatial WPD for 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 m height respectively. The colors of the spatial WPD, from cyan to purple, indicated wind power per unit swept area from low to high. Spatial WPD showed higher WPD at mountain regional. It was resulted from the computation of the WPD based on the wind map, which showed higher wind speed at mountain regional. Higher WPD at mountain regional mainly were affected by average wind speed for mountain-valley breeze which could reaching the range of 9 – 11 m/s [7].

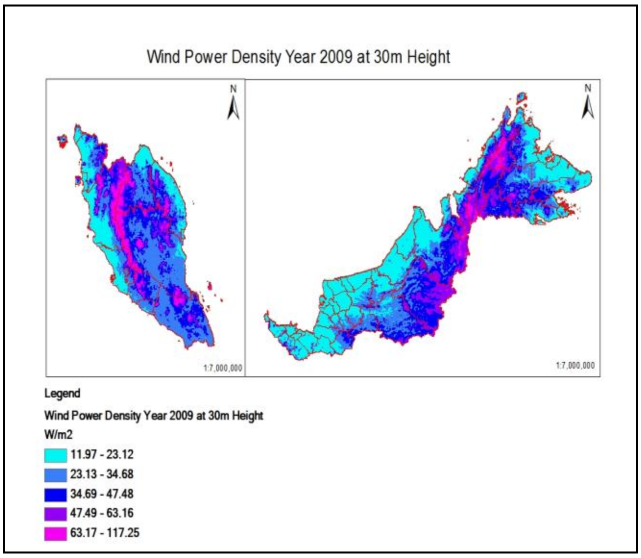
a) 10m



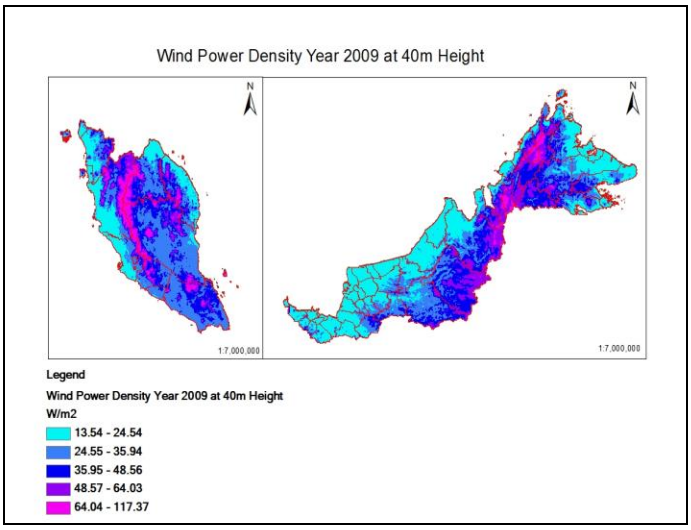
b) 20m



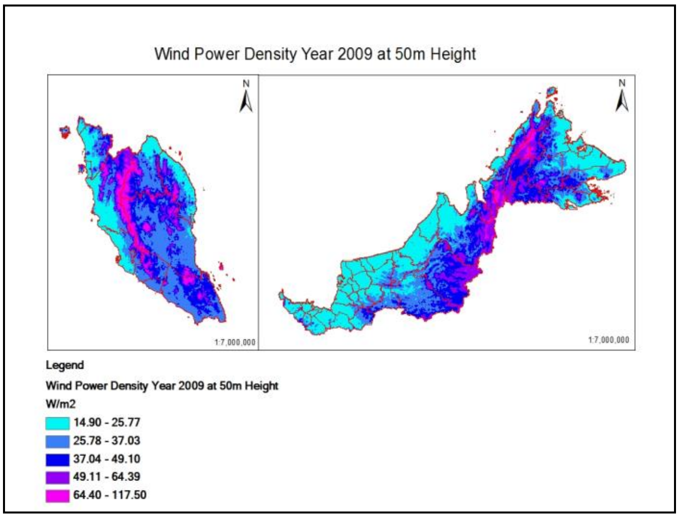
c) 30m



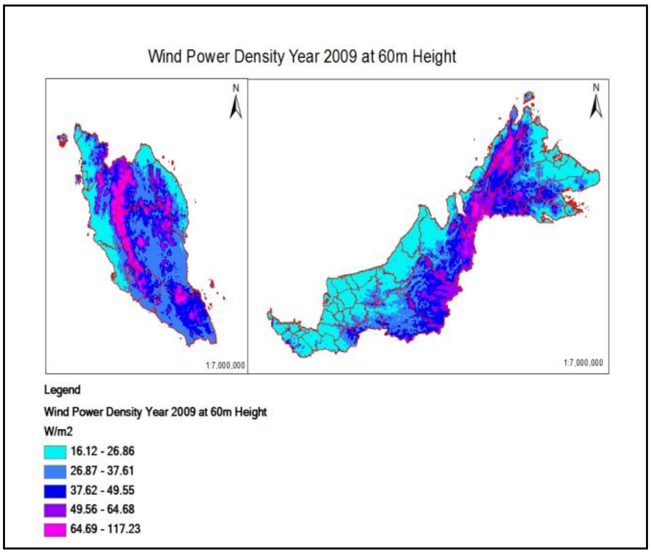
d) 40m



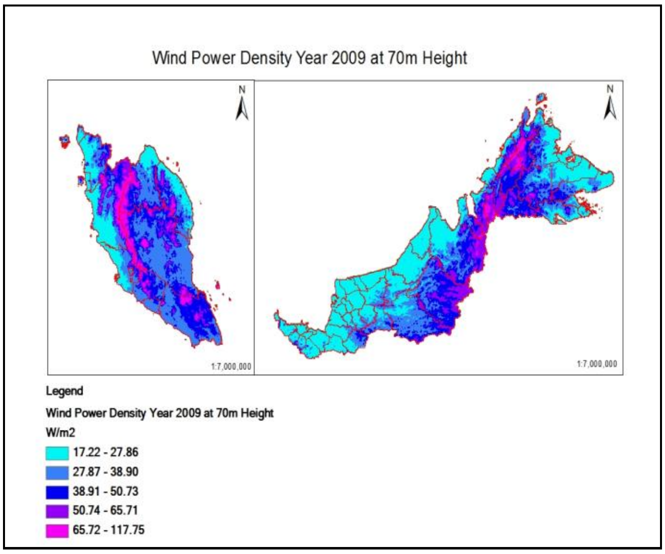
e) 50m



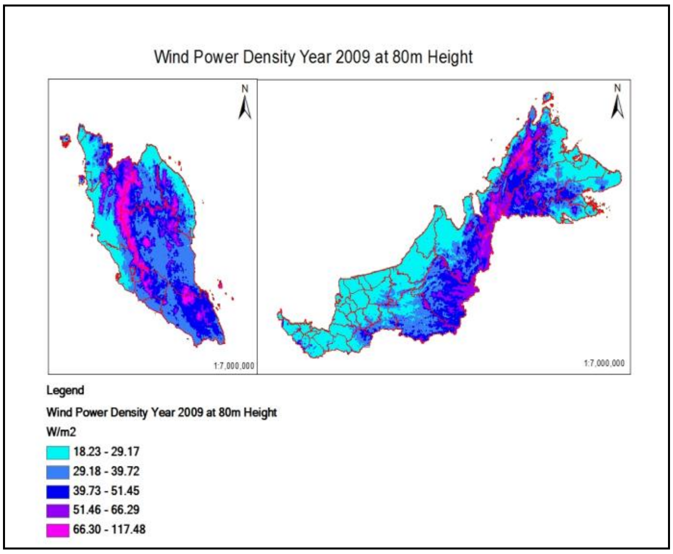
f) 60m



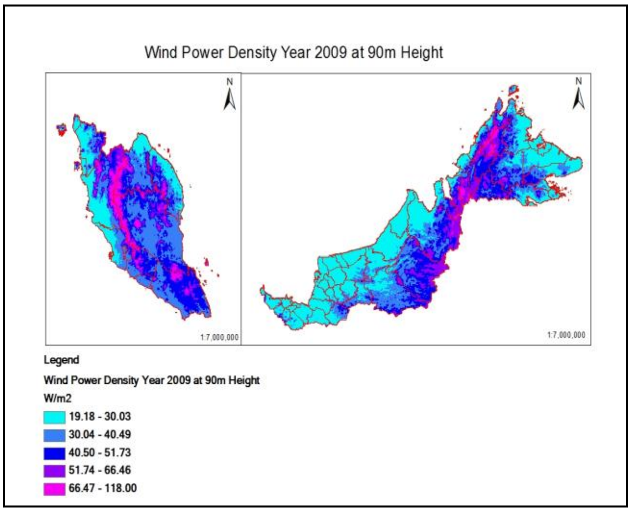
g) 70m



h) 80m



i) 90m



j) 100m

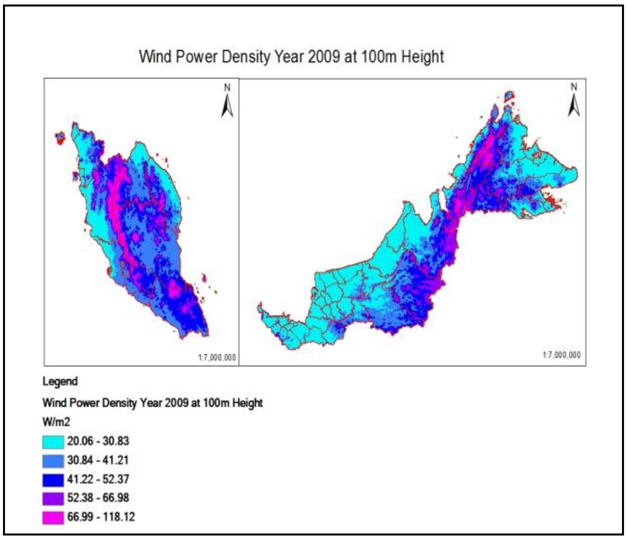


Figure 4(a-j). Spatial Wind Power Density.

Table 1 shows the wind power classes ranging from Class 1 to Class 7, with each class representing the mean wind power density and mean wind speed at 30 and 50 m heights above the ground [34]. The standards that have been used in United State since 1987 are: areas designated as class 4 or greater are generally considered to be suitable for most wind turbine applications; Class 3 areas are suitable for wind energy development if tall towers are used; Class 2 areas are marginal; and Class 1 areas are unsuitable for wind energy development [31,34]. However, these standards were updated and established into each of two categories: one for utility-scale applications (ranging from marginal to excellent) and one for rural power applications (ranging from moderate to excellent) to outfit the Philippine's wind energy potential [35].

Table 1. Classes of Wind Power Density [34]

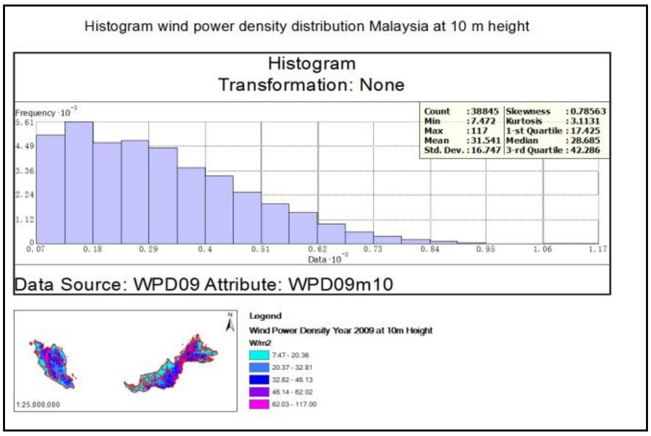
Wind Power Class	30 m		50 m	
	Wind Power Density (W/m^2)	Wind Speed (m/s)	Wind Power Density (W/m^2)	Wind Speed (m/s)
1	≤ 160	≤ 5.1	≤ 200	≤ 5.6
2	≤ 240	≤ 5.9	≤ 300	≤ 6.4
3	≤ 320	≤ 6.5	≤ 400	≤ 7.0
4	≤ 400	≤ 7.0	≤ 500	≤ 7.5
5	≤ 480	≤ 7.4	≤ 600	≤ 8.0
6	≤ 640	≤ 8.2	≤ 800	≤ 8.8
7	≤ 1600	≤ 11.0	≤ 2000	≤ 11.9

The WPD of Malaysia was falling into Class 1 (Table 1), in the range of, 11.97 – 117.25 W/m^2 at 30 m height (Figure 4(c)) and 14.90 – 117.50 W/m^2 50 m height (Figure 4(e)). Class 1 was referred to as moderate range of the rural power applications [35].

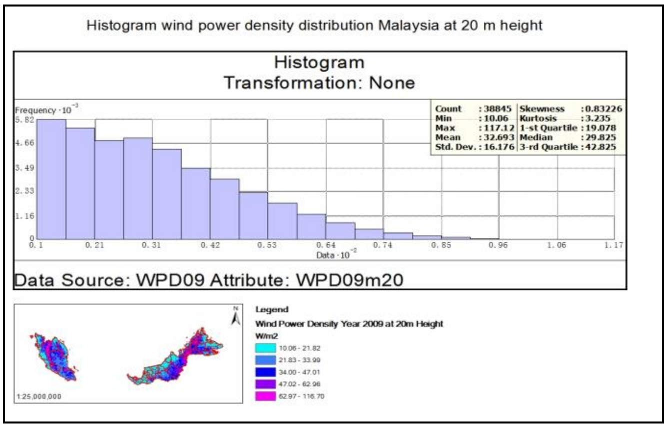
3.2. Spatial Analysis of Wind Power

The frequency distribution of the WPD for whole Malaysia for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 m height were plotted as histogram as shown in Figure 5(a-j). The results revealed that, the mean of the data set was in the range of 31.541 – 39.211 W/m^2, and the skewness for the distribution histograms was in the range of 0.7856 – 0.9278. The positive value of the skewness indicated that the distributions were skewed to the right, and the mean was greater than the median.

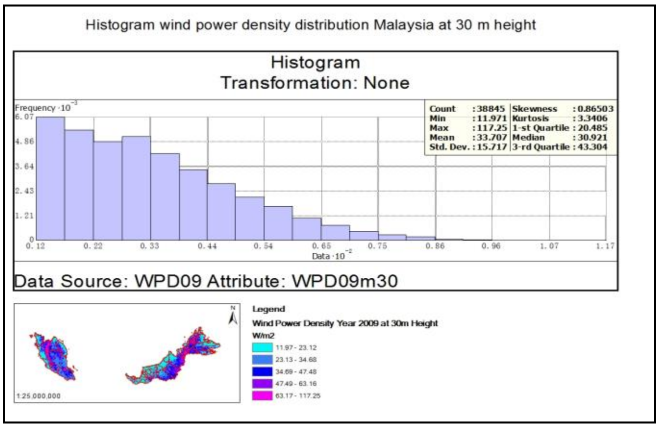
a) 10m



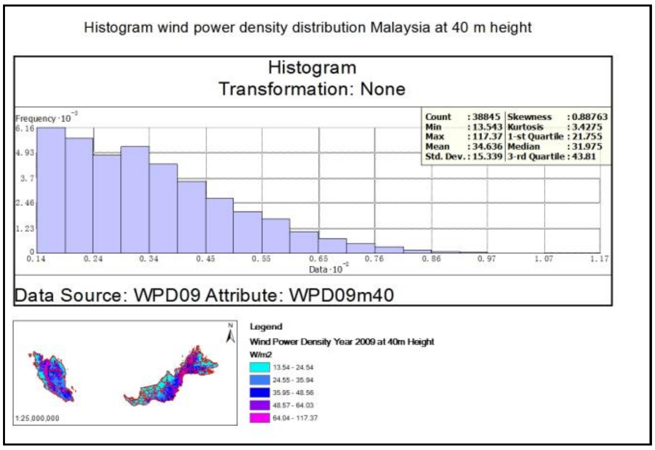
b) 20m



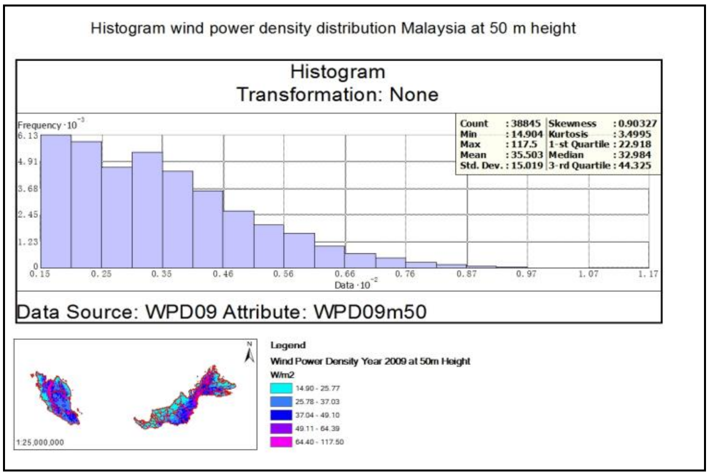
c) 30m



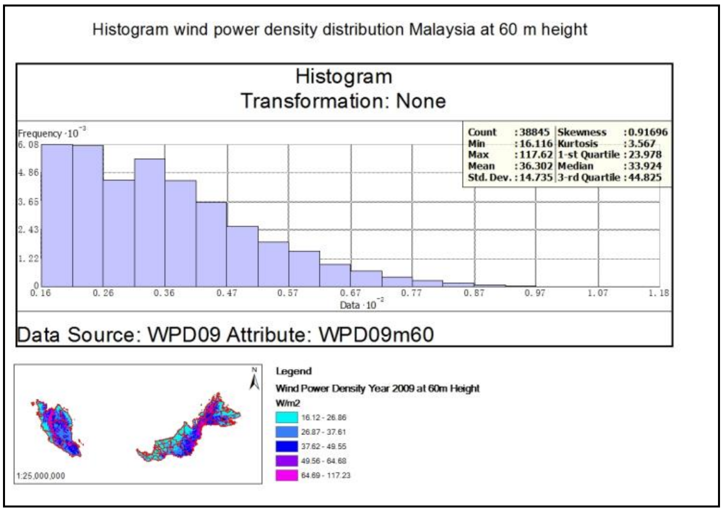
d) 40m



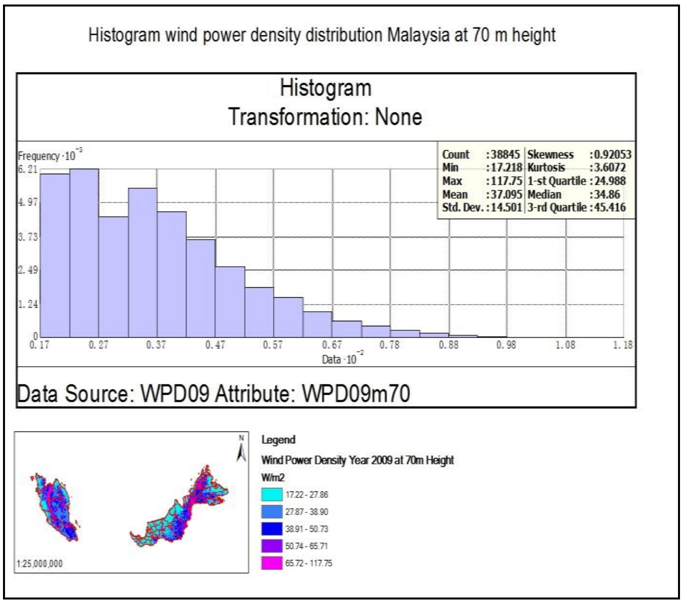
e) 50m



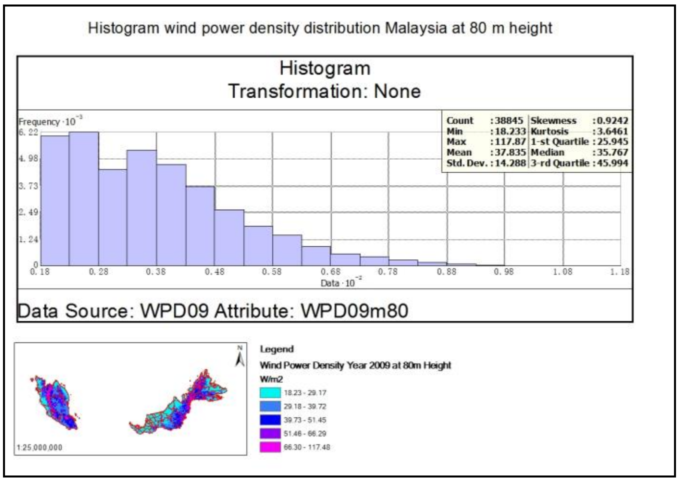
f) 60m



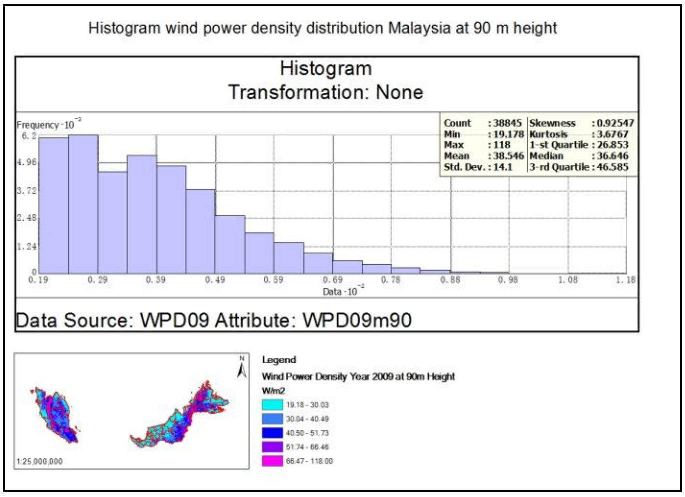
g) 70m



h) 80m



i) 90m



j) 100m

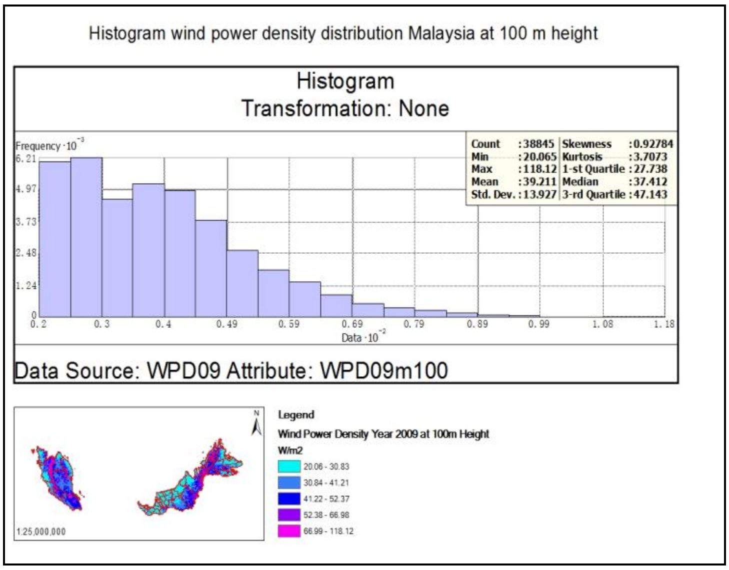


Figure 5(a-j). Histogram of the Distribution of Wind Power Density whole Malaysia.

Based on the result described in Figure 5, the total WPD in Malaysia could be calculated by multiplying the mean and the number of counts. Total WPD for whole Malaysia at different height, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 m, were summarized in Table 2. There was a greater WPD at higher height or altitude, 1.5232 MW/m^2 at 100 m height. In other word, there have at least 1.5232 MW of wind energy available to be harness.

Table 2. Total Wind Power Density for Malaysia at Different Height

Height (m)	Total WPD (MW/m^2)
10	1.2252
20	1.2699
30	1.3093
40	1.3454
50	1.3791
60	1.4101
70	1.4409
80	1.4697
90	1.4973
100	1.5232

3.3. Limitation

There were limited existing wind measurement which purposely for wind energy exploitation in Malaysia. The dependency on the secondary data caused to this study limited to one year wind data only. Five years wind data were required to obtain a reliable yearly average of wind speed [26,27], but one year wind data would be only sufficient enough to realize its potential [16]. The varying wind speed from year to year had been neglected. The wind energy exploitation or development in Malaysia shall depend on primary wind data rather than secondary wind data which were not installed for the purpose of wind resource measurement. Then, it was suggested to have at least five year data in order to carry out the study of climate change and the yearly average of wind speed variation throughout the year in Malaysia.

The dependency on the secondary data also caused to the limited number of selected wind monitoring stations or interpolation points. Addition, construction of a wind monitoring system was very costly. Hence, the points of input for the spatial wind modeling were set to as minimum as nine points. The outcome of this study, it was suggested that to have at least nine wind measurement stations for wind resource measurement purposes, and to allow measurement of wind speed in Malaysia for five year.

Besides, wind directions were not included in this study of wind potential and spatial wind modeling. Wind direction was one of the most important wind characteristics to evaluating the wind potential at a study areas [37]. Thus, the spatial wind modeling was suggested to include also the wind direction onto the wind regime as well as surface roughness on the variation of the wind profile.

4. Conclusion

WPD of Malaysia is falling into Class 1 which was referred to as moderate range of the rural power applications. Malaysia was divided into a total of 38845 raster in order to plot the histogram of WPD; the results showed that the distributions were skewed to the right. The total WPD for whole Malaysia was greater at higher height or altitude, 1.5232 MW/m^2 at 100 m height. In other words, there was at least 1.5232 MW of wind energy waiting for harnessing.

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