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MODELLING OF WIND SPEED AND POWER ACROSS JAMAICA

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ABSTRACT A simulation of the annual mean wind speed and power, and the monthly variability of wind speed and power across Jamaica were done using a numerical model and wind data (speed and direction) from three surface stations. The stations were at Munro, and at the Norman Manley and Donald Sangster International Airports. Results show that five regions can be identified as having good potential for utility-scale wind power. The regions lie in the parishes of St Elizabeth, Manchester, St Mary, St Andrew, St Thomas and Portland. The extent of the regions with useful winds (annual mean speeds > 5.0 ms^{-1} and power > 150 Wm^{-2}) vary. The smallest estimated extent is 47 km^2 in Portland and the largest is 295 km^2 in Manchester. In all the regions many locations with higher winds (annual mean speeds > 7.0 ms^{-1} and power > 325 Wm^{-2}) were observed. The study of the monthly variability of the speed and power reveals that, in all the regions, stronger wind speeds and power were recorded in February, June and July followed by October and November. Several good potential sites where wind power can be utilized in water pumping, for irrigation and domestic purposes, were also seen.

INTRODUCTION

Jamaica is a developing country in the Caribbean region. It is not endowed with domestic reserves of fossil fuel, such as oil and gas. As a result, the country is heavily dependent on imported fuels, especially petroleum[1]. Since the 1970's, there have been on and off efforts[2,3,4] to find suitable sites for wind power utilization in Jamaica, mainly for electricity generation and irrigation. These efforts have located several good potential sites for irrigation, but only a few for electricity generation, including Munro in St Elizabeth and Wigton in South Manchester. Munro and Wigton area are shown in figures 2 and 3 respectively. A Vestas 27-225 kW wind turbine now operates at Munro and plans are underway to develop a 20 MW wind farm at Wigton[5]. However, prospecting for more wind sites should continue because, firstly, wind energy has now become the most competitive source of renewable energy and a primary source around the world due to advances in technology[6]. Secondly, there is a growing demand for energy and a need to reduce the expenditure on imported fuels, the costs of which are expected to increase.

The processes of wind prospecting involved in the earlier efforts[2,3,4] had been time consuming and costly. Because of that, the investigations were concentrated on selected locations and an island wide prospecting of potential sites was less than comprehensive. Recently, Amarakoon and Chen[7,8] performed island wide preliminary surveys by mapping wind (mean speed and power) using the software WindMap v 2.21 (Brower and Co., Andover, MA 01810, USA). Results from these preliminary studies indicated that there is variability in mean wind speed and power from parish to parish with Portland, St Thomas, Manchester and St Elizabeth recording high values along with good field extent. Also there were indications of noticeable monthly variability in speed and power in any given parish.

This paper presents the results of an extended study performed using WindMap with special attention to the wind field extent, locations of high winds and monthly variability of speed and power across the parishes of St Elizabeth, Manchester, St Mary, St Andrew, St Thomas and Portland. The wind field in the parish of Clarendon was also subjected to some study to explore the feasibility of wind power in water pumping for irrigation purposes. Clarendon is a parish containing a large number of sugar cane fields, which are irrigated.

MEASUREMENTS AND DATA ANALYSIS

Software WindMap is designed to be used with geographical information systems (GIS). The surface grid resolution associated with WindMap is 1 km x 1 km. The data required to execute WindMap are hourly wind speeds and directions from surface stations or upper air level data, elevation and roughness parameters defined on a 1 km x 1 km grid, and the horizontal cartesian coordinates (x and y coordinates) of the data stations referenced to a suitable origin.

This work used wind data from the surface stations Munro, Norman Manley and Donald Sangster Airports. Table 1 presents the physical characteristics of these stations, period of data collection, wind measuring heights, annual mean wind speed and predominant wind direction from north. Wind speeds and directions used in the analysis were hourly values. Raw data from Munro, Manley and Sangster were 10 minute values. These raw data were reduced to hourly values using software WinSite[9] and Excel. Munro data were recorded by a Maximum #40 anemometer and wind vane set, and the data at the Norman Manley and Donald Sangster International Airports by Casella London anemometer and wind vane sets. The Meteorological Office of Jamaica provided wind data from Norman Manley and Donald Sangster. The Physics Department of the Mona Campus, UWI possessed wind data from Munro; Digitized satellite maps purchased from Brower and Company, Andover, MA, USA provided the required elevation and roughness parameters on a 1 km x 1 km grid scale.

Data analysis consisted of executing the software WindMap under unstable atmospheric scenario with Munro as the reference station, mapping of regions having useful wind (for electricity generation and water pumping) on a 1 km x 1 km grid, estimating the area of the mapped regions, and estimating the area average (spatial average) of wind speeds and power across the mapped regions. Selection of one data station as the reference station is required in WindMap. The reference station provides the frequency of wind by direction to all the stations used in initializing the model. The primary reason for choosing one station as the reference station is the need to optimize execution time that has to accommodate many iterations. In our work Munro was chosen as the reference station, because Munro was an inland site and the anemometer-vane system at 30m was well exposed to wind. The studies of Chen et al.[10] have shown that the atmosphere in the vicinity of Mandeville is unstable and Munro is in the neighbouring parish. Thus, execution of the model was done under unstable atmospheric scenario.

RESULTS

Figures 1 to 12 and Table 2 present the results obtained in this study. Figures 1(a) and 1 (b) were maps created by WindMap and edited using the GIS software ILWIS[11] to illustrate the distribution of annual mean wind speed and power across Jamaica. The darker the region, the higher is the speed or power. From the results provided by these two maps, the six regions labeled 1 to 5 and I-R were selected for some detail investigation. Table 2 presents the classification of these regions in terms of the parishes to which they belong. Figures 2 to 12 present the results obtained for the wind speeds, power, shape and the extent of the wind fields. Studies of Amarakoon and Chen[7,8] revealed that WindMap satisfactorily simulates annual and monthly mean wind speeds. The percentage deviations between the simulated and measured mean wind speeds were less than 14%. As such there was no need to validate the model. The speeds and power shown in the figures are at the 40m level. This level is suitable for hub heights of many of the existing utility scale wind turbines with rated power of about 225 kW to 1 MW. Rotor diameters of these machines may range from 27 m to about 50 m. In water pumping, however, smaller turbines (rated power of about 10 to 50 kW) can be used. The x and y coordinates given in Figures 2 to 7 are defined in a system where the north Negril point has the coordinates 146 km and 2033 km. The magnitudes of the areas given in the Figures were estimated using a 1 km x 1 km mesh.

TABLE 1 Names of the Surface Stations, their Physical Characteristics (Elevation and Roughness), Data Collection Period and Number of Data Hours, Wind (Speed and Direction) Measuring Heights, Annual Mean Wind Speed, and Predominant Wind Direction from North.

Station	Elevation (m)	Roughness (m)	Data Period & Hours	Height (m)	Wind Speed (ms^{-1})	Direction (degrees)
Munro	766	0.2	8, '96-7, '97 (8750 hours)	30	7.17	90
Manley	0 (sea level)	0.001	1, '98-12, '98 (8340 hours)	10	4.06	120
Sangster	0 (sea level)	0.001	9, '96-8, '97 (7925 hours)	10	3.82	30

TABLE 2 Classification of the Regions in Terms of the Parishes

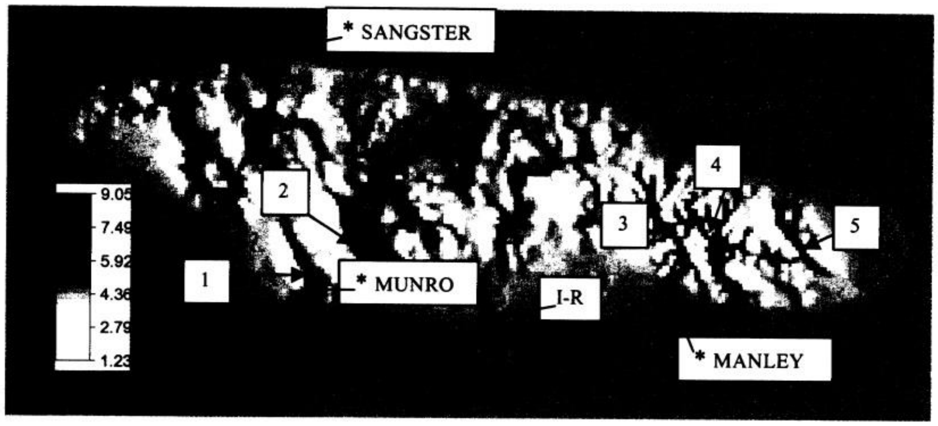
Region	Enclosed Parish(es)
1	St Elizabeth
2	Manchester
3	South East of St Mary, South West of Portland and North East of St Andrew
4	Portland and St Thomas
5	East Portland
I-R[a]	Clarendon

[a] Irrigated Region

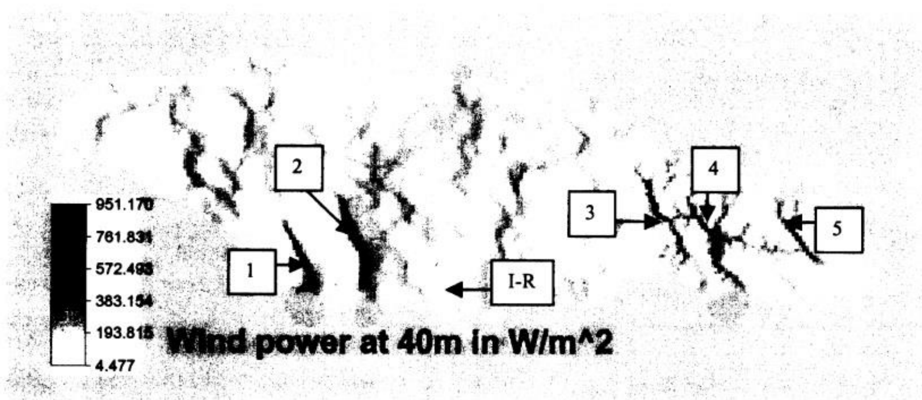
DISCUSSION AND CONCLUSION

The regions shown in Figures 2 to 6 enclose areas with annual mean wind speeds > 5.0 ms^{-1} and power > 150 Wm^{-2}, and locations having speeds > 7.0 ms^{-1} and power > 325 Wm^{-2} are indicated. These speed and power values were chosen based on the information given in Wind Energy Information Guide[12] for rural and utility-scale applications. The estimated areas of these regions vary from 295 km^2 (region 2) to 47 km^2 (region 5). A significant number of locations with strong winds (speeds > 7.0 ms^{-1}) are seen in all the regions. But the number of locations with strong winds is higher in regions 2 and 4 compared to the other regions. A topographical feature common to all the regions is the fact that they have hilly terrain. Based on a land area of 0.16 km^2 per megawatt of installed capacity in hilly terrain (AWEA[13]), all the regions appear suitable for wind farming. In this regard, the proposed wind farm in the parish of Manchester (Wright[5]) supports the results in our work. Figures 8 to 12 show the monthly variability of wind speed and power across these regions. The values of speed and power are given as area averages. February and the summer months June and July record high speed and also power in all the regions. These months are followed by October and November.

Figure 7 shows an area in the parish of Clarendon enclosing many sugar fields. It is a section of the Monymusk sugar estate. This estate is irrigated[14], as the annual rainfall in the area is insufficient to sustain the growth of sugar cane throughout the year. As stated in the annual report[14], problems of reduced and unreliable water supply from the Monymusk night storage reservoir exist. Perhaps, one way to meet the water demand for irrigation is to supply water by other means, such as wind power driven water pumping, in addition to the night storage reservoir. Sites in the region shown in Figure 7 appear to have annual mean wind speeds greater than 3.4 ms^{-1} and the area averaged wind speed is 4.5 ms^{-1}. Small wind turbines operate satisfactorily in sites with speeds greater than about 3.5 ms^{-1} [12,15]. Thus, it is practical to consider the utilization of small turbines to pump underground water in the Monymusk area, to meet the water demand for irrigation. The turbines may be used



(a)



(b)

FIGURE 1(a) A Simulated Wind Map of Jamaica Showing the Annual Mean Wind Speed Distribution across the Country at 40m, Data Stations and the Study Regions

FIGURE 1(b) A Simulated Wind Map of Jamaica showing the Annual Mean Wind Power Distribution across the Country at 40m and the Study Region

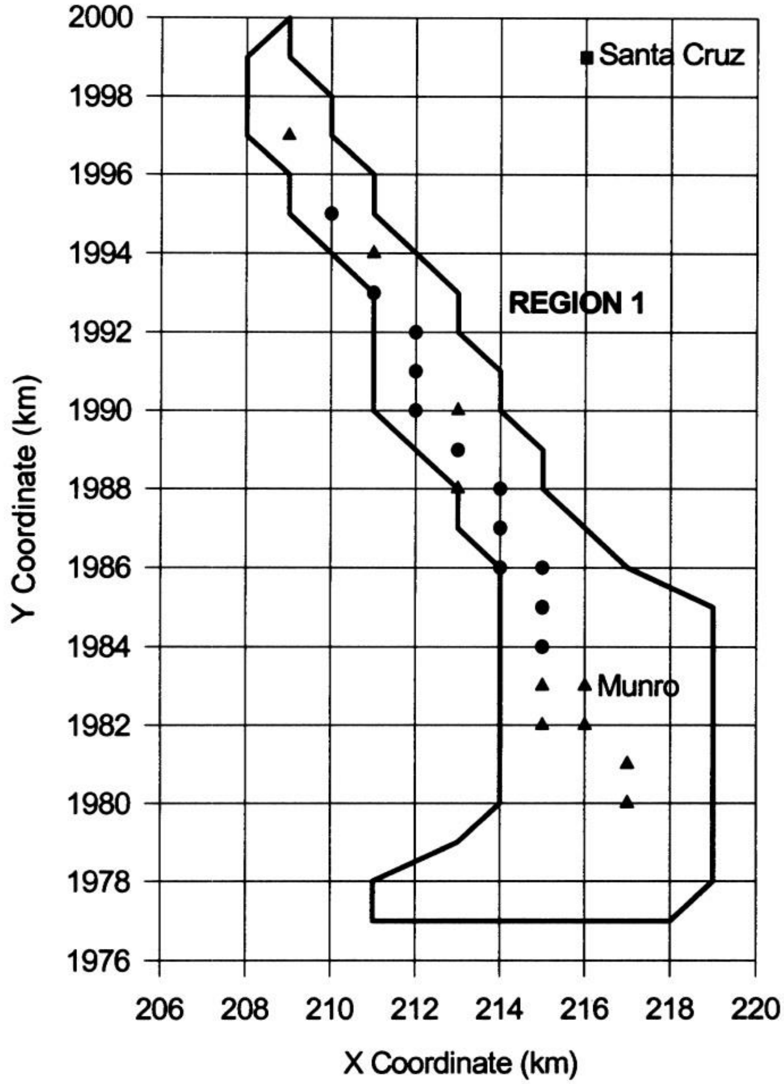


FIGURE 2 **Map of Region 1 - Filled Circles and Triangles represent High Wind Locations. The Coordinates X and Y are Defined in a System where the North Negril Point has the Coordinates 146 km and 2033 km. Locations of Munro and Santa Cruz are Shown**

Area average of annual mean wind speed = 6.23 ms^{-1}
Area average of annual mean wind power = 314.8 Wm^{-2}
Estimated area of the wind field = 79.5 km^2

LEGEND FOR THE MARKED HIGH WIND SITES:
Triangles: 7.0 < mean wind speed $\leq$ 7.6 ms^{-1}
Circles: 7.6 < mean wind speed $\leq$ 8.2 ms^{-1}

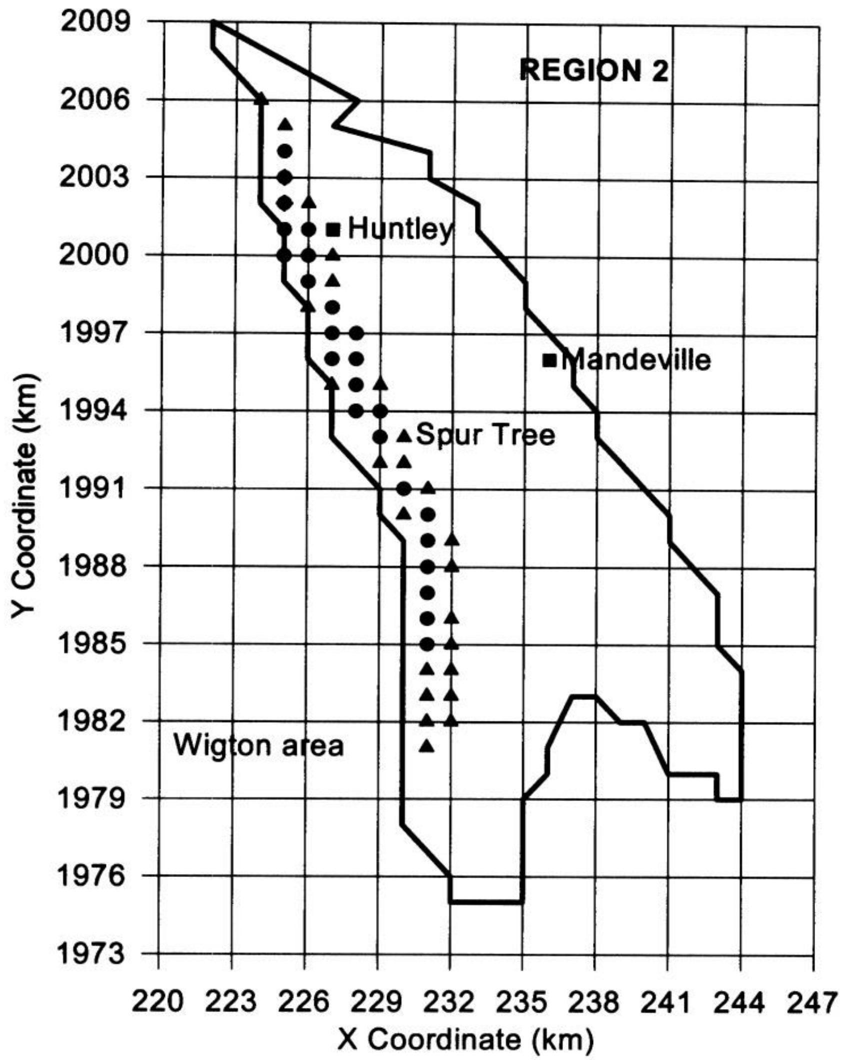


FIGURE 3 **Map of Region 2 - Filled Circles, Triangles and Diamonds represent High Wind Locations. The Coordinates X and Y are Defined in a System where the North Negril Point has the Coordinates 146 km and 2033 km. Locations of Huntley, Mandeville, Spur Tree and Wigton area are Shown**

Area average of annual mean wind speed = 6.1 ms^{-1}
Area average of annual mean wind power = 287.6 Wm^{-2}
Estimated area of the wind field = 295.0 km^2

LEGEND FOR THE MARKED HIGH WIND SITES:
Triangles: 7.0 < mean wind speed $\leq$ 7.6 ms^{-1}
Circles: 7.6 < mean wind speed $\leq$ 8.2 ms^{-1}
Diamonds: 8.3 < mean wind speed $\leq$ 8.7 ms^{-1}

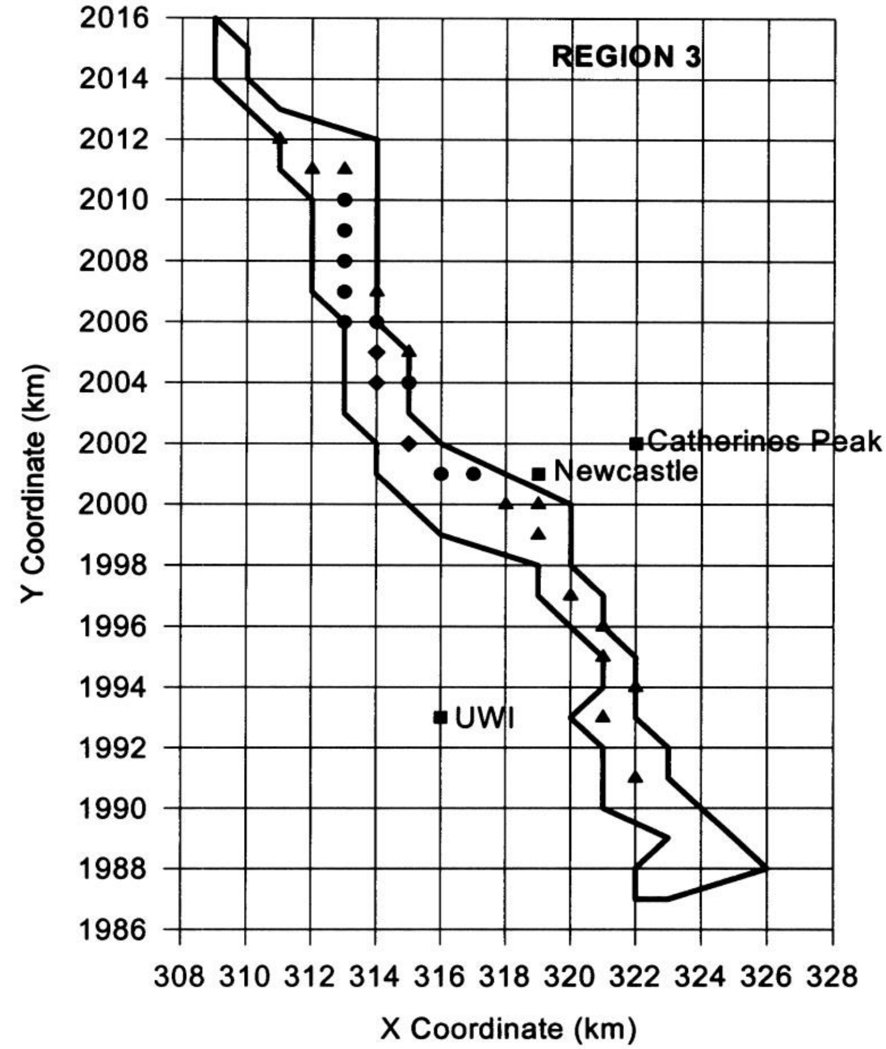


FIGURE 4 **Map of Region 3 - Filled Circles, Triangles and Diamonds represent High Wind Locations. The Coordinates X and Y are Defined in a System where the North Negril Point has the Coordinates 146 km and 2033 km. Locations of Catherines Peak, Newcastle and UWI are Shown**

Area average of annual mean wind speed = 6.4 ms^{-1}
Area average of annual mean wind power = 328.5 Wm^{-2}
Estimated area of the wind field = 61.5 km^2

LEGEND FOR THE MARKED HIGH WIND SITES:
Triangles: 7.0 < mean wind speed ≤ 7.6 ms^{-1}
Circles: 7.6 < mean wind speed ≤ 8.3 ms^{-1}
Diamonds: 8.3 < mean wind speed ≤ 9.1 ms^{-1}

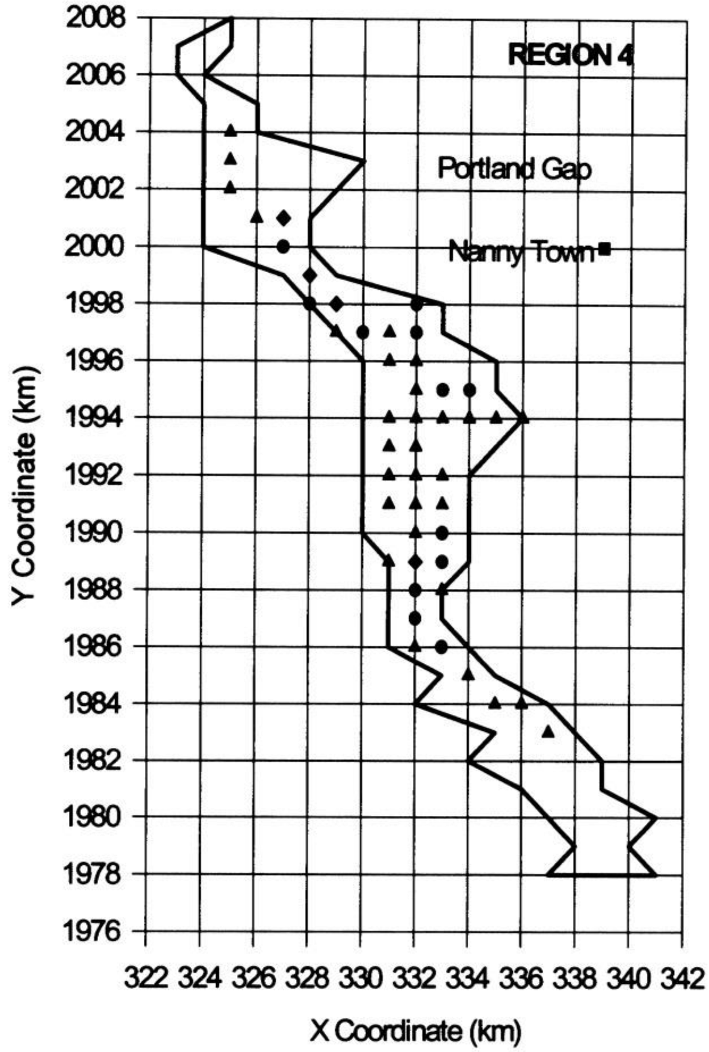


FIGURE 5 **Map of Region 4 - Filled Circles, Triangles and Diamonds represent High Wind Locations. The Coordinates X and Y are Defined in a System where the North Negril Point has the Coordinates 146 km and 2033 km. Locations of Nanny Town and Portland Gap are Shown**

Area average of annual mean wind speed = 6.4 ms^{-1}
Area average of annual mean wind power = 339.2 Wm^{-2}
Estimated area of the wind field = 106 km^2

LEGEND FOR THE MARKED HIGH WIND SITES:
Triangles: 7.0 < mean wind speed $\leq$ 7.6 ms^{-1}
Circles: 7.6 < mean wind speed $\leq$ 8.3 ms^{-1}
Diamonds: 8.3 < mean wind speed $\leq$ 9.0 ms^{-1}

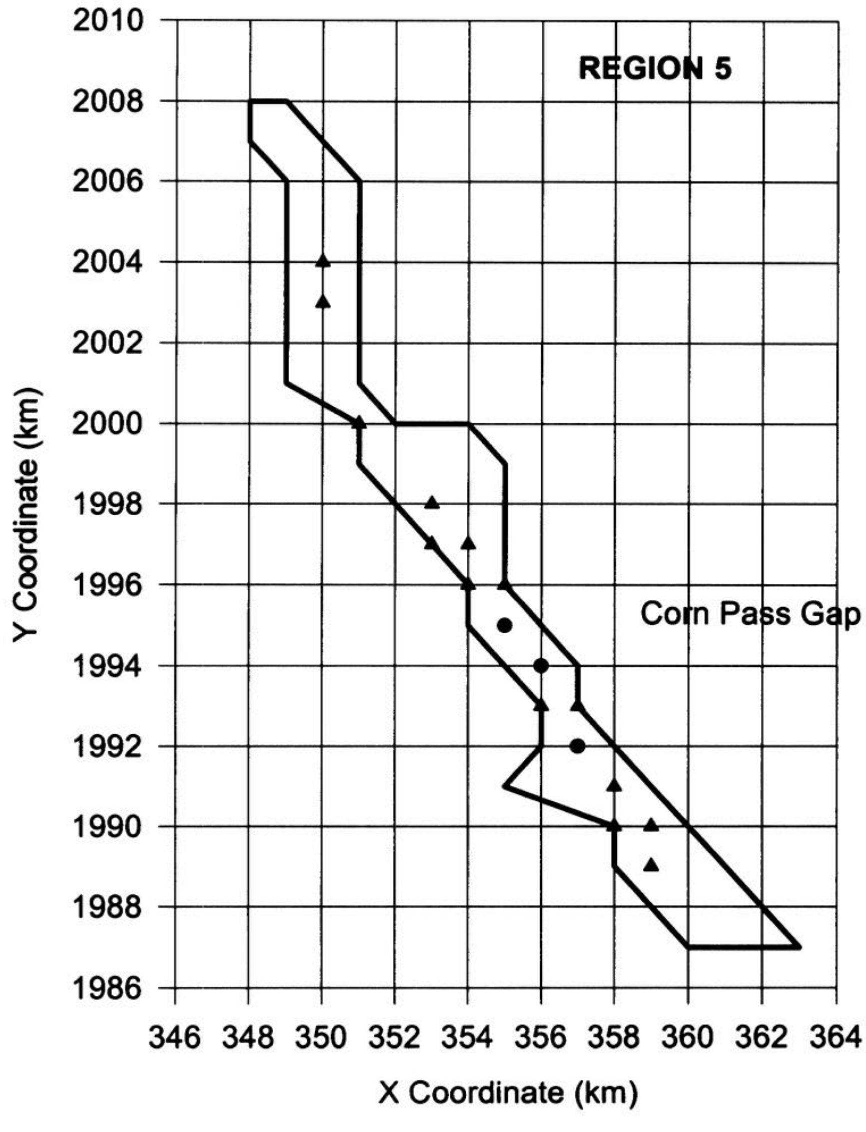


FIGURE 6 **Map of Region 5 - Filled Circles and Triangles represent High Wind Locations. The Coordinates X and Y are Defined in a System where the North Negril Point has the Coordinates 146 km and 2033 km. Location of Corn Pass Gap (highly windy area) is Shown**

Area average of annual mean wind speed = 6.1 ms^{-1}
Area average of annual mean wind power = 292 Wm^{-2}
Estimated area of the wind field = 47 km^2

LEGEND FOR THE MARKED HIGH WIND SITES:
Triangles: 7.0 < mean wind speed $\leq$ 7.6 ms^{-1}
Circles: 7.6 < mean wind speed $\leq$ 8.3 ms^{-1}

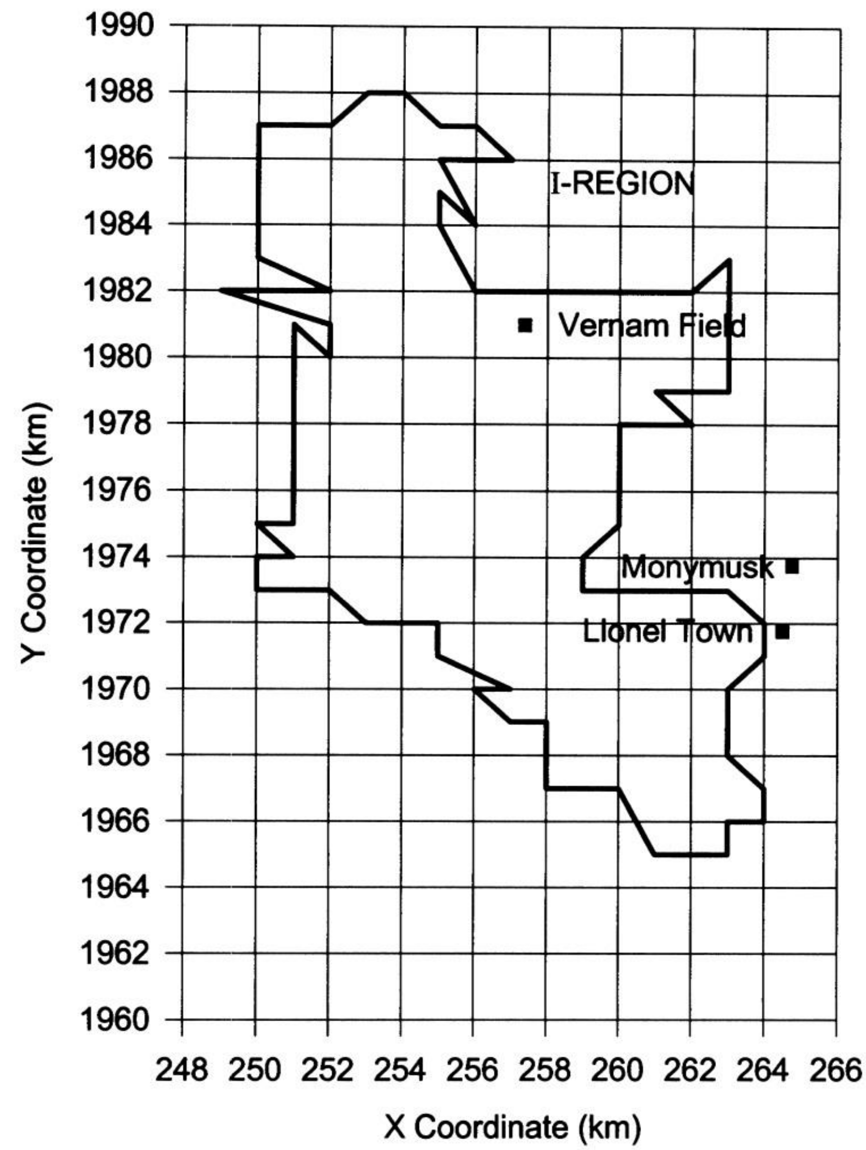


FIGURE 7 **Map of I-region (Irrigated region). The Coordinates X and Y are defined in a System where the North Negril Point has the Coordinates 146 km and 2033 km. The Region is a part of the Monymusk Sugar Estate. Locations of Vernam Field, Monymusk and Lionel Town are Shown**

Area average of annual mean wind speed = 4.5 ms^{-1}
Area average of annual mean wind power = 110.5 Wm^{-2}
Estimated area of the wind field = 173 km^2

Spatial variation of the mean wind speed: 3.4 to 5.0 ms^{-1}

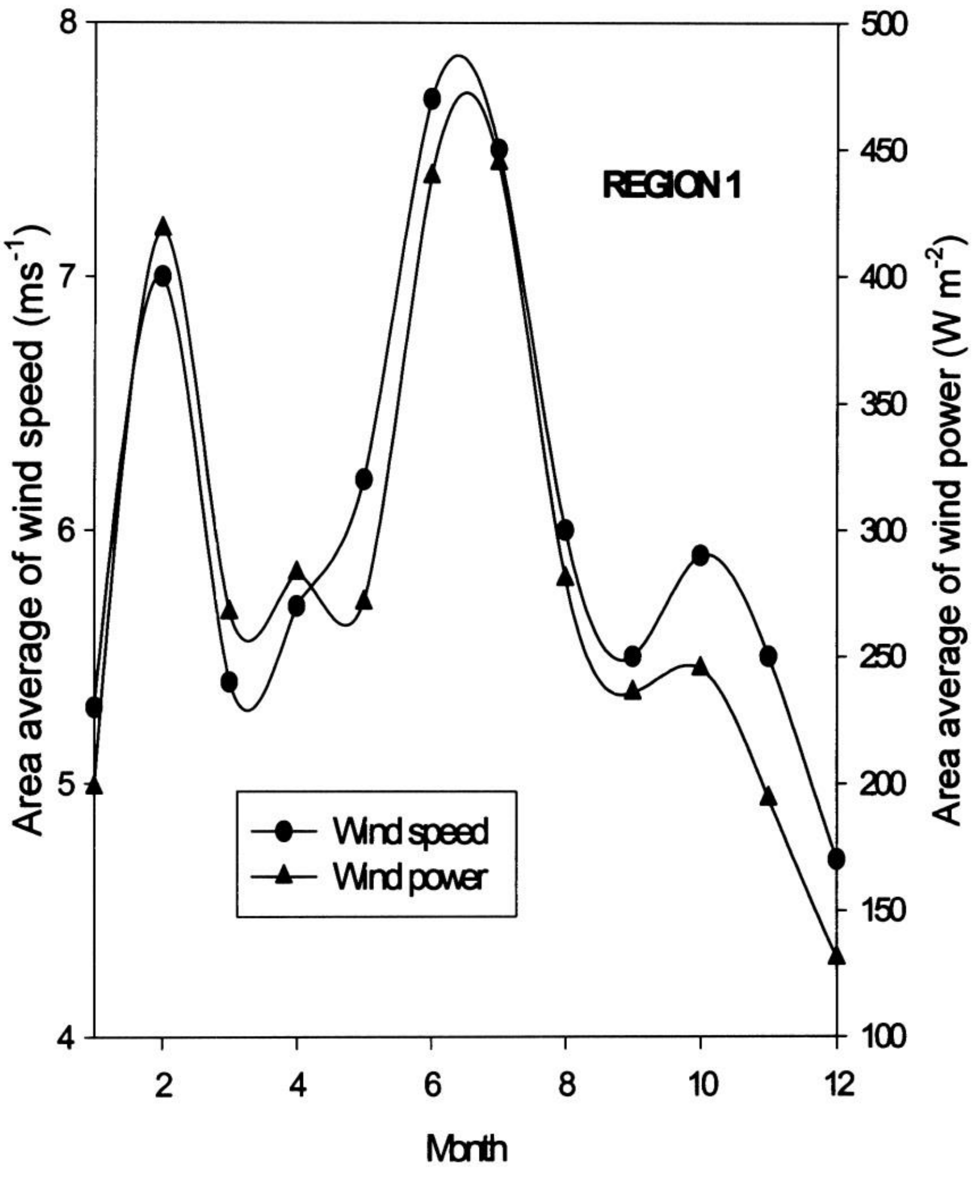


FIGURE 8 Monthly Variability of Area Average Wind Speed and Power in Region 1

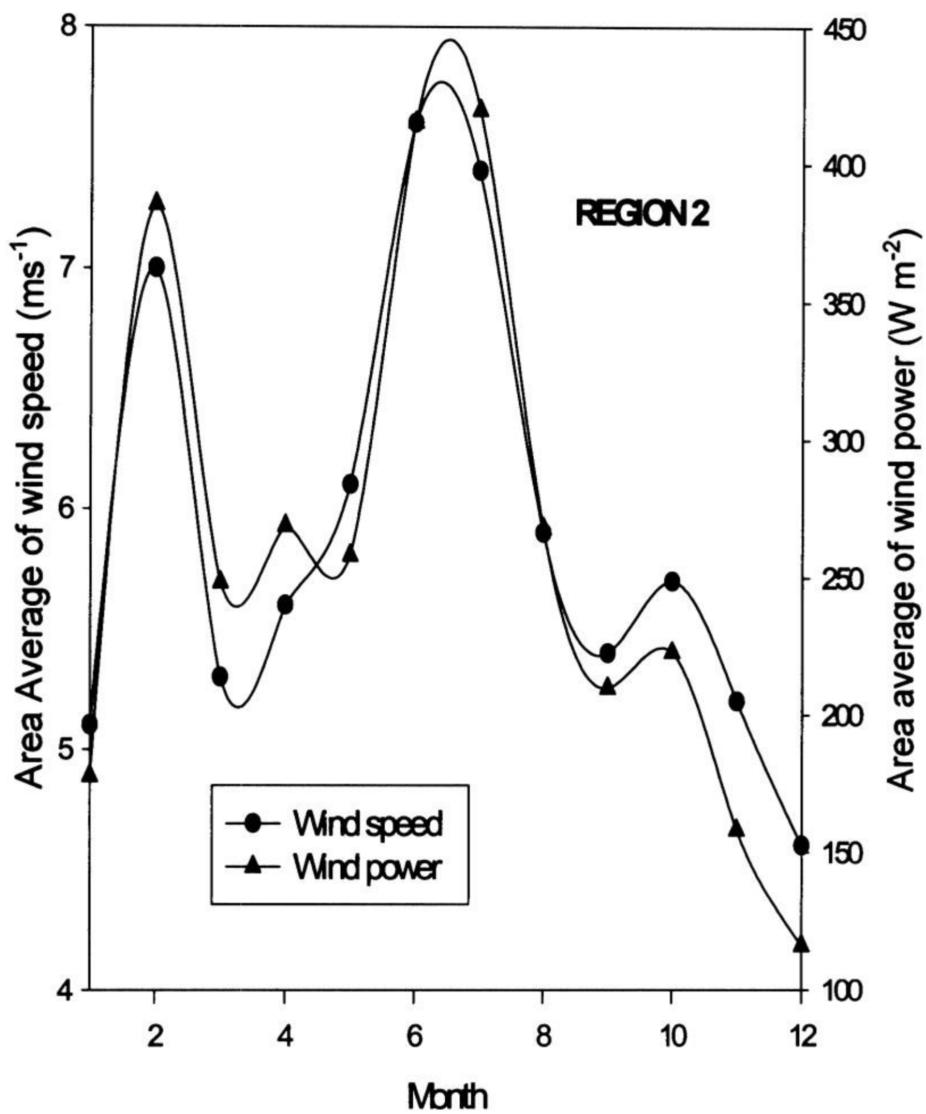


FIGURE 9 **Monthly Variability of Area Average Wind Speed and Power in Region 2**

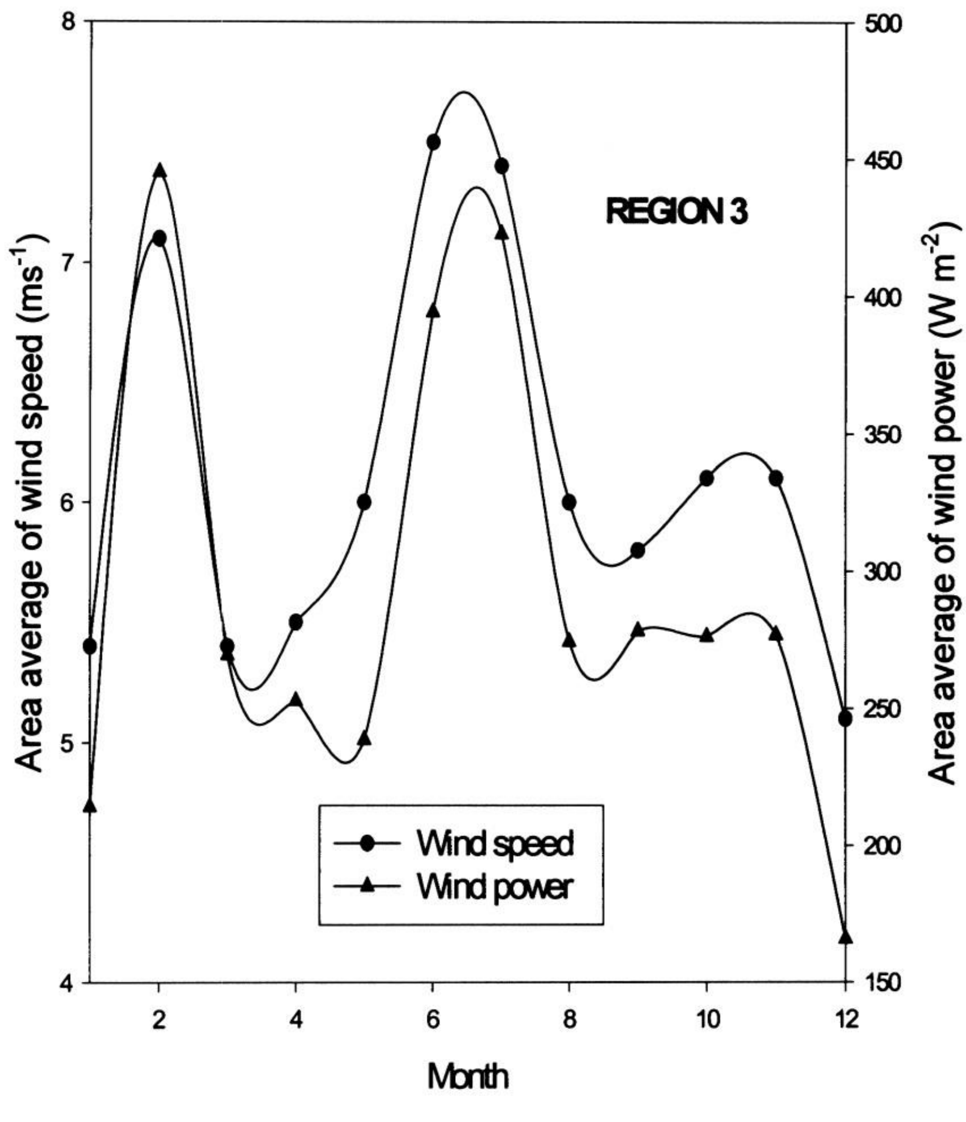


FIGURE 10 Monthly Variability of Area Average Wind Speed and Power in Region 3

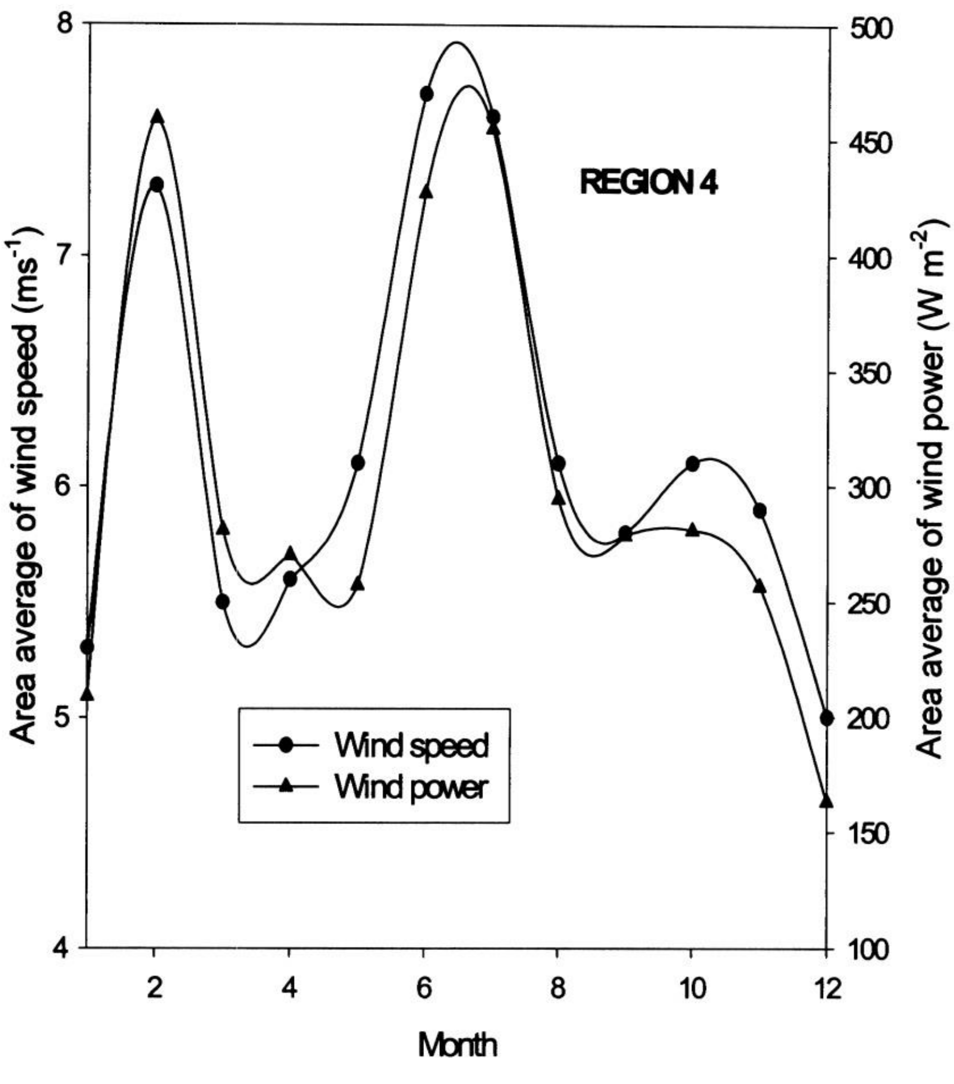


FIGURE 11 Monthly Variability of Area Average Wind Speed and Power in Region 4

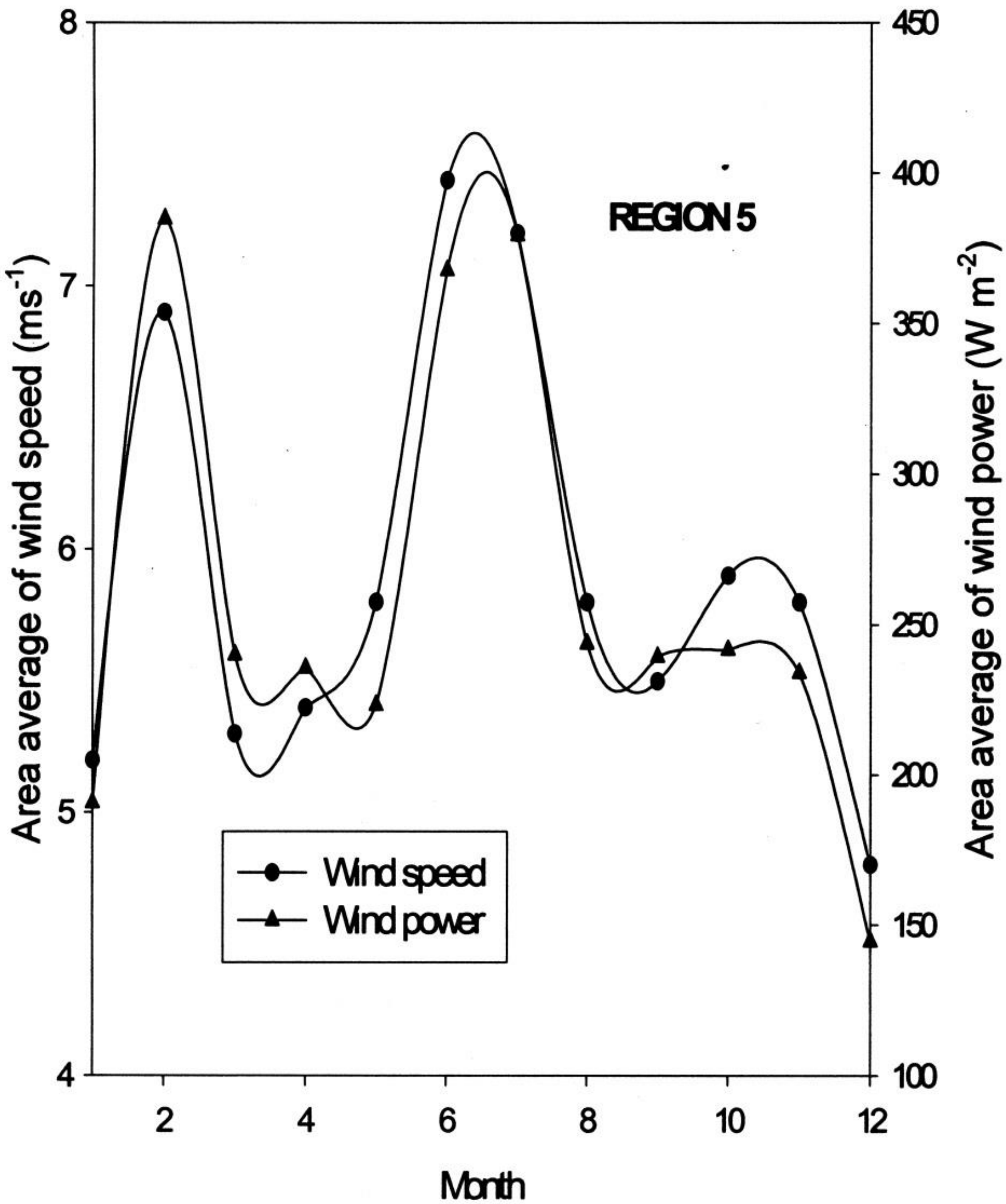


FIGURE 12 Monthly Variability of Area Average Wind Speed and Power in Region 5

to generate electrical energy to the estate, when not in use for water pumping. This is an advantage. There are several other parishes, in addition to Clarendon, where wind power can be utilized for water pumping. Examples are Westmoreland, Trelawny, St Ann.

This study has identified several regions having potential for wind power development, by a low cost and a time conserving method. The results support the earlier findings of Chen[2], Chen et al.[3], and Wright[4]. The resolution of the model used in this work is 1 km x 1 km and the number of input data stations used in the mapping is 3, which were limitations. But the results obtained are useful. Economic feasibility is a factor that has to be considered in large-scale wind power projects in developing countries like Jamaica. A Study done by Chen and Amarakoon[16] revealed that electrical energy from wind could be produced in Jamaica at competitive prices, but the economic feasibility may depend largely on the initial investment scenario. However, today, wind energy is a primary source of energy in many parts of the world and the cost of wind generated electricity is expected to slide down significantly with the improvements in wind turbine technology. In the year 2002, the cost is expected to be 3 to 4 US Cents per kWh[13]. Considering the growing status of wind power development around the world today, based on the acceptance of wind power as a non-polluting and environmentally friendly source and the decrease in the cost of wind generated electricity, it is worthwhile for energy developers to explore wind power in Jamaica in greater depth.

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