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Study of Wind Speed and Wind Potential at Kagbeni, Thini and Palpa in Nepal

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Abstract:

The primary objective of this paper is to study and analyze the wind characteristics and power potential at the three different places in Nepal. One year of wind speed data measured at 10 m and 20m height above ground level, provided by the Department of Alternative Energy Promotion Center, have been analyzed in this study. Direct use of data including the mathematics of probability and statistics has been applied to compute the wind power potential of the proposed sites with the occurrence of effective wind speed between cut-in and cut-out speed. The diurnal wind speed variation analysis of the three different sites showed that higher wind speed occurred during the daytime and reached a maximum at 3 PM whereas the lowest wind speed occurred after midnight and achieved a minimum at 7 AM to 8 AM. On basis of wind energy potential, Kagbeni has an annual potential energy of 3.98MWhr/m^2 at 10m height and 4.82MWhr/m^2 at 20m height while Palpa has the potential of 0.27MWhr/m^2 and 0.36MWhr/m^2 at the two heights with wind speed more or equal to 3m/s. Similarly, Thini has potential of 2.4MWhr/m^2 and 2.9MWhr/m^2 at 10m and 20m height on the limit of above wind speed. On the monthly basis, Kagbeni and Thini have the highest average wind speed in June whereas Palpa has in March and April. Likewise the highest value of wind speed at Kagbeni, Palpa and Thani are found as 22.53m/s and 21.75m/s; 17.66m/s and 17.11m/s, and 17.9m/s and 7.3m/s in April and March at heights of 10m and 20m respectively.

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1. INTRODUCTION

Energy is universally recognized as the most crucial aspect of economic growth and human development in any country. Energy derived from wind has played a vital role in the history of mankind and is again receiving considerable attention because of its free and non-polluting character. Wind energy is the kinetic energy generated by the effect of air currents which is transformed into other forms and useful for several human activities [1]. Wind speed is a fundamental atmospheric quantity caused by the movement of air from high to low pressure due to temperature changes. The power is extracted by allowing it to blow past on blades that exert torque on a rotor. The amount of power transferred dependent on the rotor size, its position, and wind speed [2] Wind is one of the fastest-growing renewable energy sources for power generation and has become more competitive with conventional energy sources in the recent year [3]. The wind speed probability distribution determines the performance of a wind energy generation system for a particular location. With the gradual development in wind energy technologies and a relative decrease in production cost, it has shown remarkable development around the world over the last two decades [4, 5]. According to the Global Wind Energy Council (GWEC) report global offshore wind capacity will surge to over 234 GW by 2030. Europe remained the largest market for offshore wind energy at the end of 2019, making up 75% of total global installations. It seems that Europe will continue to be a leader in offshore wind, with a goal of 450GW by 2050. According to the GWEC report countries in the Asia Pacific region, such as Taiwan, Vietnam, Japan, and South Korea are quickly picking up the pace and will be regions of significant growth in the next decade [6].

Nepal, a land-locked country with a total area of 147, 181 square kilometers, is located between 26^0 $26^'$ to 30^0 $26^'$ North latitude and between 80^0 $03^'$ to 88^0 $15^'$ East latitudes. The elevation of the terrain ranges from 70m to 8,848m from sea level. It is 17 % of the total land is flat (Terrain), 68%is covered by hills and the remaining 15% is covered by high mountains. So, there is wide diversity in landscape, altitude, topography, and temperature in the nation [7]. In Nepal, most of the energy requirement is fulfilled by the utilization of fossil fuels. Excessive utilization of fossil fuels leads to the degradation of the environment. It causes problems like global warming, acid rains, and climate change [8] that we are facing. Energy from renewable resources will play an important role in this situation. The utilization of wind energy, like any other natural resource requires detailed information of its availability. Continuous wind speed is the most important factor to estimate the wind resource potential at any location. Due to high variability of topography, temperature, and altitude, wind energy mapping in Nepal is complicated and expensive. The past effort neither came up in the complete picture of wind resource of the country nor borrowed the work carried out by the outsiders [9]. The nation's renewable energy subsidy policy of 2000 highlighted the importance of wind energy for meeting the nation's energy demand. The policy also highly prioritized the need for data collection and wind map preparation including financial support to attract investors [10] and also The Rural Energy Policy 2006 aims to prepare Wind Energy Master Plan for effective deployment of potential wind energy resources [11]. The assessment of wind resources is the basis of wind power utilization. The solar and wind energy resources Assessment pointed out the need for further analysis and research for a complete assessment to identify the micro-level potential of the wind resource in Nepal [12]. At present, renewable energy technologies are the priority of the Government. Micro/mini hydropower and Solar photovoltaic are disseminated through existing renewable energy policy in off-grid areas of Nepal for rural electrification and operating enterprises and income-generating activities.

Out of the total generated electricity, 1233 MW is from hydroelectricity, 54 MW from the thermal plant, and 68 MW from renewable energy. In the fiscal year of 2018/19, the import of electricity from India was 2,813.07 GW hours, but in the current fiscal year 2019/20, the import of electricity has decreased by almost half to 1,468.77 GW hour. Also, by the end of mid-March of the fiscal year 2019/20, about 10 % of the total population has access to electricity from renewable energy sources. About 764kW of renewable energy has been used from micro and small hydropower projects and 50kW from solar and wind energy in the same period [13]. A study [14] conducted showed a technical and financial analysis of wind energy resources of a 15 MW wind farm in Mustang for power generation. In general, wind speeds are grouped into four categories [15]: i) minimum 2 m/s, which is required to start rotating most small wind-turbines, ii) 3.5 m/s, the typical cut-in speed, where a small turbine starts generating power, iii) 10–15 m/s, which produces maximum generation power, and iv) 25 m/s, the cutout speed. The cut-in speed and cut-out speed are the operating limits of the turbine.

2. DATASET AND THEORETICAL MODEL

Wind speeds are found changing as months and seasons vary. Here we have discussed the wind energy potential of three important places Kagbeni, Palpa, and Thini of Nepal. One year of wind speed data measured at 10 m and 20m height above ground level, provided by the Department of Alternative Energy Promotion Center, have been analyzed in this study.

A suitable approach mentioned in the direct method of data analysis [16] has been developed for the extrapolation of wind energy potential. Wind power at a site can be obtained by a device mounted on a pole at a different fixed height of the wind generator. In general, the available wind generation capacity is determined by average wind speed over the year for each location. Consider a packet of air with mass m moving with speed v and its K E is given by $\frac{1}{2}\, m\, v^2$. The power associated with the wind is defined as energy per unit time.

Now the power $P = \frac{Energy}{Time} = \frac{1}{2}$ x Mass crossing through area A x v^2

$$= \frac{1}{2}\ (\mathrm{m} \times A / \mathrm{time})\ \mathrm{v}^2 = \frac{1}{2}\ (\rho A v\ )\, v^2$$

Wind power density (P) is a measure of wind resources in a specified site. It is well known that flows at v through a blade swept area (A= 1) increases as the cube of its velocity and given by [16, 17]

$$P = \frac{1}{2}\rho\, A\, v^3 = \frac{1}{2}\rho\ v^3 \tag{1}$$

In S I unit P is wind power density; ρ is air density (kg/m^3) at studied region. A typical value used in all the literature is average air density of 1.225 kg/m^3 corresponding to a standard condition of 1 atm and 15^{0}C, v is wind speed normal to the surface area A. Thus, the wind power density is usually used to measure the theoretical potential of wind and is independent of the wind turbine types. It represents the available wind energy at a site and has a unit W/m^2. The theoretical potential of wind resources based on wind power density is greater than actual wind power generation due to the wind power curve feature of the wind turbine. So wind power density is not used directly in calculating energy production but is an indicator of the overall wind resource of the site.

The cubic relationship between powers in the wind velocity tells us that we can't determine the average power in the wind by simply substituting wind speed in equation (1). This can be done by rewriting the above nonlinear characteristic of wind by rewriting it in terms of average values. The monthly mean or average wind speed v_{avg} of the time-series of measured hourly wind speed data obtained from the Alternative Energy Promotion Center (AEPC) can be determined from the equation below

$$v_{avg} = \frac{1}{N}\sum_{i=1}^{N} v_i \tag{2}$$

and average power in the wind is

$$P_{avg} = \frac{1}{2}\rho\ (\ v^3)_{avg} \tag{3}$$

Where, v_{avg} , mean wind speed (m/s); v_i is hourly wind speeds(m/s) and N, number of measured hourly wind speed data. The wind power density is the number of watts of electrical energy produced per square meter of air space (W/m^2). Wind power density is a measure of the capacity of wind resources in a specific site. The average wind power density (WPD) is the average available wind power per unit area and is measured by

$$P_{avg} = 0.5 \times \rho \times v_{avg}^3 \tag{4}$$

Where,

$$v_{avg}^3 = \sum_i v_i^3 \times\ (\mathit{fraction\ of\ hours\ at}\ v_i) \tag{5}$$

P_{avg} is average wind power density expressed as W/m^2, ρ is the average air density in kg/m^3. Air is a mixture of different molecules existing in a certain percentage [16]. It is calculated using the following expression

$$\rho = 1.225\ \text{-}(1.94 \times 10^{-4}) \times Z \tag{6}$$

where Z = the height of the location of the turbine above sea level expressed in Meter.

3. RESULTS AND DISCUSSION

The assessment of wind resources is the basis of wind power utilization. An accurate and comprehensive characterization of the wind resource is of vital importance to site planning wind turbine selection. The Data of wind speeds collected from the Department of Alternative Energy Promotion Center for three different places of Nepal at two different heights, 10 m and 20m above ground level have been analyzed in this study. We have here computed and discussed the wind energy potential of three important places Kagbeni, Palpa, and Thini of which we are interested in wind energy as a renewable source of energy. First we studied the diurnal and monthly average minimum and maximum wind speeds at the three different places at 10 m and 20m heights. The diurnal wind speed variation pattern at three places has been shown in the Figures below.

3.1. Annual Diurnal Wind Speed Variation

The three important sites have the same trends of wind speeds having different magnitudes. They are disused below. The annual diurnal wind speed pattern at Kagbeni (Figure **1**) shows that wind speed reaches its minimum during the first 7 hours in the morning and the peak is at 15th hour both 10m and 20m heights having 14.25 m/s and 15 m/s respectively, but at Palpa (Figure **2**) minimum wind speed is observed in between 9 to 10th hours in the morning and maximum in between 16th and 18th hours in the afternoon for 10 m and 20 m heights having peak values of 4.55 m/s and 5.1 m/s respectively.

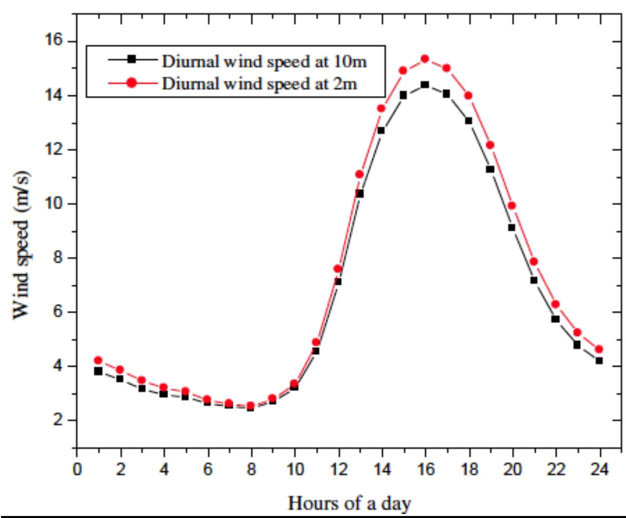

Figure 1: Diurnal variation of wind speedat 10m and 20m (2004), Kagbeni.

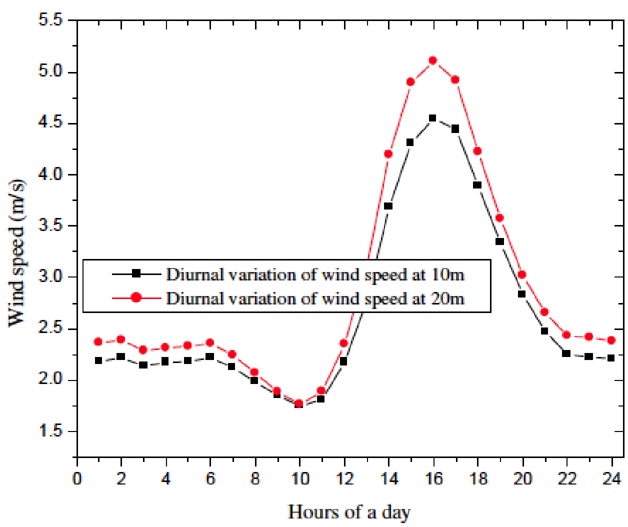

Figure 2: Diurnal variation of wind speed at 10m and 20m (2004), Palpa.

Likewise, Thini (Figure **3**) has minimum wind speeds around the 8th hour in the morning while the maximum is in between 14th and 15th hours in the afternoon at both10m and 20m heights having values 14.33 m/s and 15.33m/s. From this analysis, all three plots show a similar pattern that is the sites are windier after midday while lower during the morning and night.

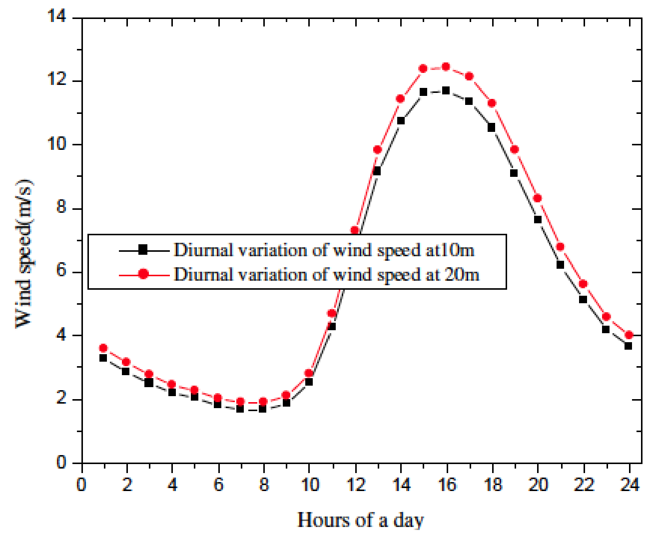

Figure 3: Diurnal variation of wind speed at 10m and 20m (2004) Thini.

The wind speed of Palpa shows lower values compared to the other two sites but pattern of variation is the same. It might be due to geographical situations. From this analysis, all the three plots show a similar pattern that is the sites are windier after midday while lower during the morning and night.

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3.2. Monthly Average Wind Speed Values

The monthly variation pattern of average wind speed at 10m and 20m height at three different places have been shown in Figures **4**, **5** and **6** below.

At Kagbeni the monthly average wind speed is highest in June (9.04 m/s and 9.7 m/s) and lowest in January (4.73 m/s and 4.95 m/s) respectively at 10m and 20m. It has symmetrical i.e., wind speed gradually increases with coming months up to June and then decreases

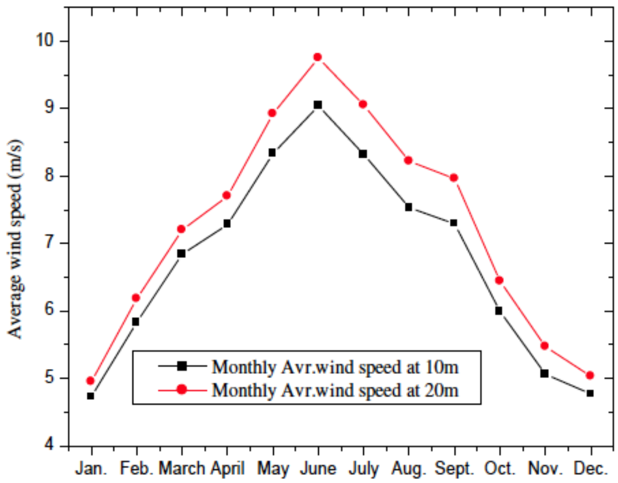

Figure 4: Monthly variation of average wind speed at 10m and 20m (2004), Kagbeni.

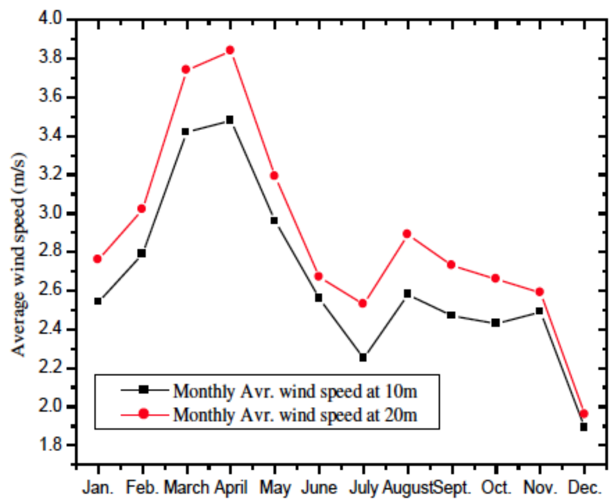

Figure 5: Monthly variation of average wind speed at 10m and 20m (2004), Palpa.

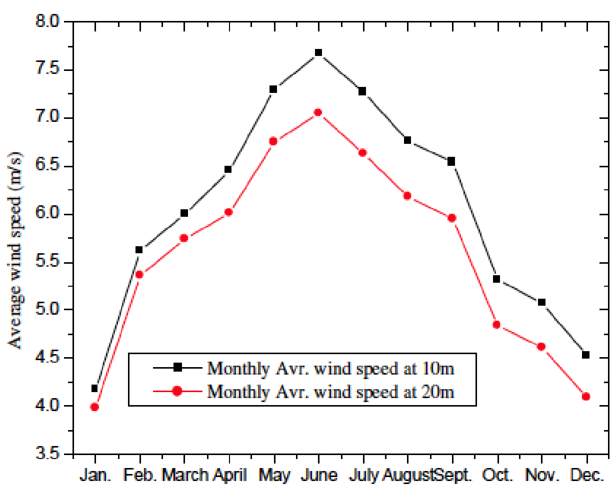

Figure 6: Monthly variation of average wind speed at 10m and 20m (2004), Thini.

gradually as shown in Figure **4**. Our second site is Palpa, where wind speed is highest in April (3.5 m/s and 3.8 m/s) and lowest in December (1.89 m/s and 1.96 m/s) respectively at 10m and 20m as shown in Figure **6**. After May the value of average wind speed falls below the cut-off range of 3.5m/s. There exist some fluctuations after May 2004 in monthly wind velocities. The third site is Thini, the average wind speed is highest in June (7.05 m/s and 7.67 m/s) while it is lowest in January (3.98 m/s and 4.17 m/s) respectively at heights 10m and 20m as shown in Figure **6**.

It is seen that out of the three sites, Kagbeni and Thini have average wind speed which falls in the above cut off the range and uses full for the extraction of wind energy whereas Palpa has very short duration i.e. from March to April of 2004. Rest months of the year are not supposed to be very useful.

3.3. Monthly Average Minimum and Maximum Wind Speed

From the data of wind speeds of each month, the average of minimum and average of maximum have been calculated for the three different sites and have been shown in Figures **7**, **8** and **9**.

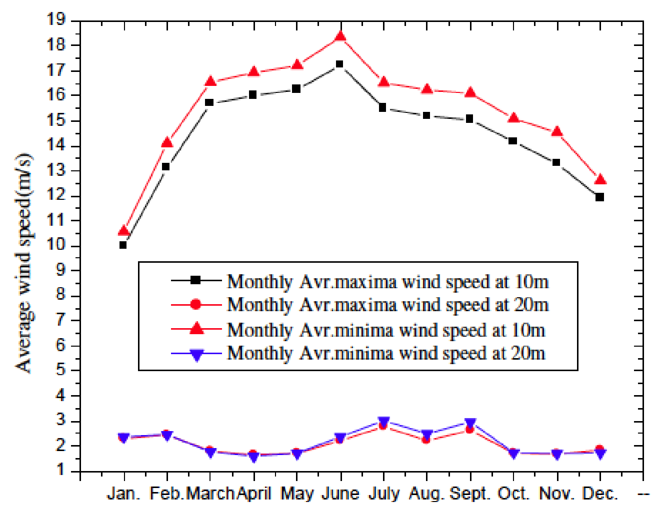

Figure 7: Monthly average max^m and min^m wind speed at 10m and 20m (2004, Kagbeni).

The monthly variations in average minimum and an average maximum of wind speed at Kagbeni have been shown in Figure **7**. The peak value of the average maximum falls in June and is 17.23m/s and 18.35m/s for 10m and 20m height respectively. As discussed earlier, the monthly average value also lies in June.

The nature of variation of wind speed is symmetrical i.e. its values increases from 10m/s (January) to maximum values in June and then decreases gradually to 12m/s in December respectively at at 10m and 20m. April and November are the months of lowest average minimum wind speeds at 10m (1.65m/s and 1.68m/s) while 20m height in April (1.59m/s) has the lowest average minimum wind speeds. For the case of Palpa (as shown in Figure **8**), the average maximum wind speed isis 6.16m/s and 7.18 m/s and the average minimum is 1.05m/s and 1.13 m/s respectively at 10m and 20m in March. The monthly average minimum falls in February and December whose values are 1.75m/s and below 1m/s.

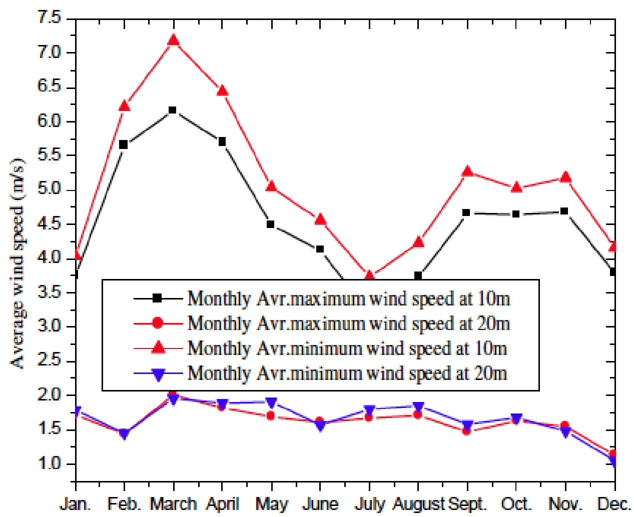

Figure 8: Monthly average max^{m} and min^{m} wind speed at 10m and 20m (2004, Palpa).

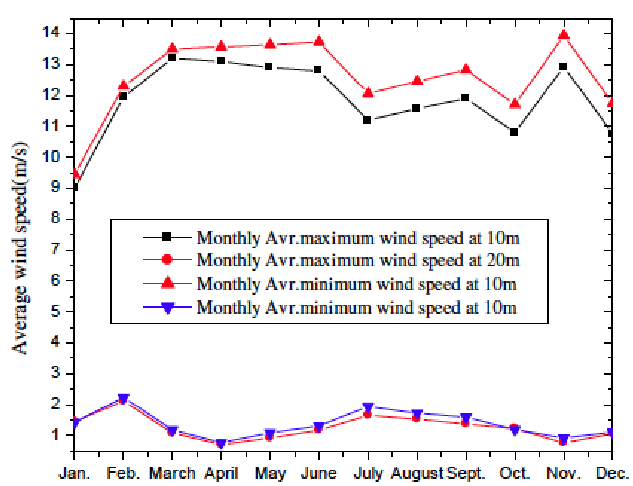

Figure 9: Monthly max^{m} and min^{m} average wind speed at 10m and 20m (2004, Thini).

Likewise, the variations of monthly average minimum and maximum at Thini have been shown in Figure **9**. Its maximum values lie between March to June and in November. The two maximum values 13.2m/s and 13.7 m/s at heights 10m and 20m, respectively. The average minimum is around 0.76m/s 0.77 m/s in April and November.

The extreme maximum wind speeds at Kagbeni, Palpa, and Thini are found as 22.53m/s on 13th April at 15 hrs, 17.66m/s on 17th April at 19 hrs, and 17.9m/s 8th March at 16 hrs respectively at 20m height. Similarly, at 10 m heights, the extreme maximum wind speeds at these stations are found as 21.75 m/s on 13th April at 15hrs, 17.11 m/s on 17th April at 17hrs, and 17.3m/s on 8th March at 16 hrs respectively.

3.4. Wind Energy Potential

We have calculated total wind energy potential and the percentage of wind speeds distribution in each month for speeds greater than 3.5m/s (cut-in speed) of the three sites from the data received. This is the threshold speed for generating power from wind. Figure **10** gives a monthly variation of wind potential energy of Kagbeni shows that the number of hourly data of each month that are useful for the extraction of wind energy ($\geq$ 3.5m/s) is found in July (91.67%) and total wind potential energy of the year 2004 is greater in June (571.73KWhr/m^2) at height of 10m.

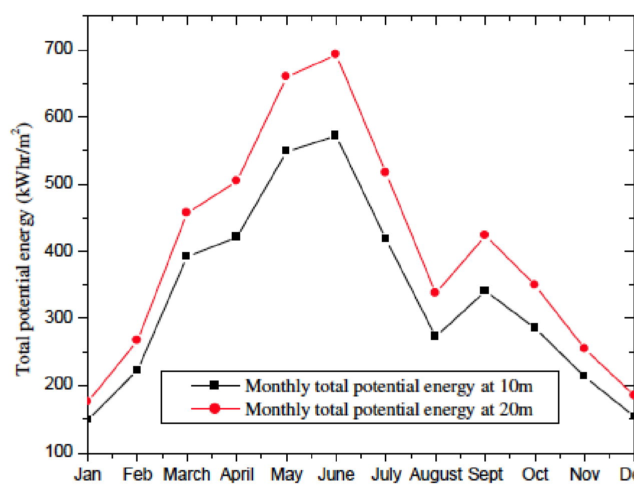

Figure 10: Monthly total potential energy at 10m and 20m (2004, Kagbeni).

On the other hand, the number of hourly data of each month that are useful for the extraction of wind energy ($\geq$ 3.5m/s) is found in July (92.47%) and the total monthly wind potential energy of the year 2004 is greater in June(692.44kWhr/m^2) at height of 10m. This shows that the wind turbine being at a height of 20m gives more wind energy compared to the turbine at 10m height. Figure **11** gives a monthly variation of the wind potential energy of Palpa. This shows that the number of hourly data of each month that are useful for the extraction of wind energy (≥ 3.5m/s) is found in April (53.19%) and also the wind potential energy is greater in April (44 kWhr/m^2) at a height of 10m. On the other hand, the greater number of hourly data that are useful for the extraction of wind energy (≥ 3.5m/s) is also found in April (57.64 %), and total wind potential energy in a month for the year 2004 is in April (59.58kWhr/m^2) at height of 20m. This shows that wind turbine being at a height of 20m gives more wind energy compared to the turbine at 10m height.

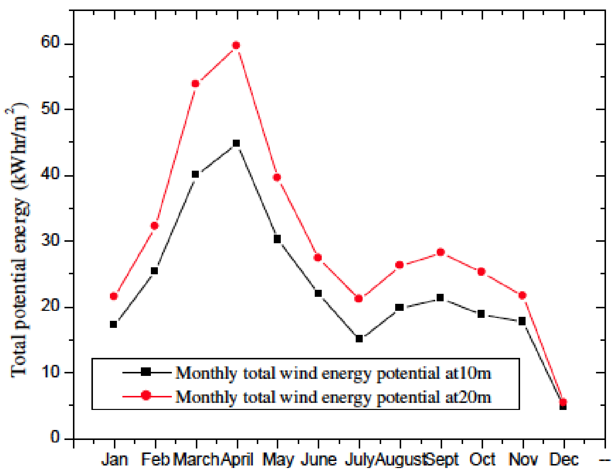

Figure 11: Monthly total wind energy potential at 10m and 20m (2004, Palpa).

At Thini, in the same way, Figure **12** gives monthly variation of wind potential energy of Thini shows that the average cut-in wind speed (≥ 3.5m/s) were 80.78% (in July) and 83.1% (in August) of the total time of a month and total maximum potential energyfor the height, 20m are 302.41 kWhr/m^2(in May) and 363 kWhr/m^2(in May) at 10m and 20m heights respectively. The total annual extraction of wind energy in 2004, at three sites considered Kagbeni, Palpa, and Thini are 3988.61 kWhr/m^2, 276.79 kWhr/m^2 and 2404.92 kWhr/m^2 at height 10m and 4822.01 kWhr/m^2, 361 kWhr/m^2 and 2938.71 kWhr/m^2 respectively at turbine's height of 20m. This reveals that a turbine height of 20m is more useful than 10m.

The energy potential graph at Kagbeni (Figure **10**) shows that the peak wind energy potentials in June and September whereas at Palpa (Figure **11**) it is in April and September and at Thini, (Figure **12**) it is in May, September, and November both at 10m and 20m heights respectively.

At Kagbeni and Palpa, the energy potential is high during the months of high average wind speeds but at Thini, however, though the average wind speed is relatively higher in June, the energy potential is found high in May. It is due to low frequency for high wind speed values and high frequency for low-speed values. For a threshold value of 3.5 m/s wind speed, it was found that Kagbeni and Thini had a wind speed equal to or greater than 3m/s for more than 50% of the annual time while Palpa had it for less than 35% of annual time. Analysis shows that the two stations Kagbeni and Thini have similar characteristics as both stations lie in the Kaligandaki valley, which is presumably the deepest gorge on earth, and winds in this valley are channelized up to the valley.

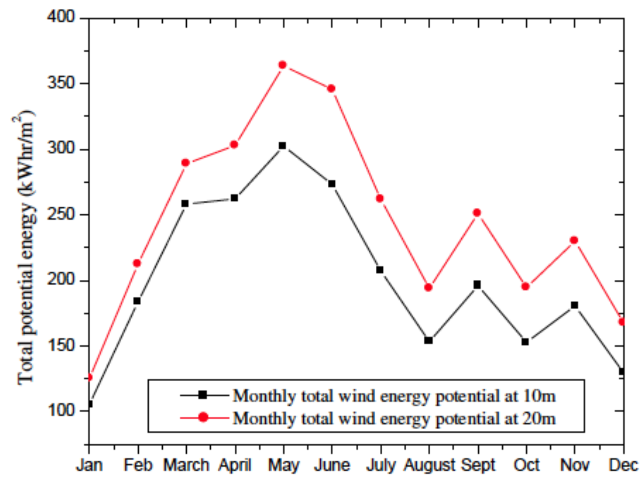

Figure 12: Monthly total wind energy potential at 10m and 20m (2004, Thini).

4. CONCLUSION

Nepal has complex and varied topography within a short span of area. The elevation of the country ranges between 70m and 8848m from the sea level. In this study, the wind speed and wind energy potential in selected three locations Kagbeni, Palpa, and Thini in Nepal have been studied. The finding from this study can be summarized as follows.

1. The diurnal wind speed variation analysis of the three sites showed that higher wind speed occurred during the daytime and reached a maximum at 3 p.m whereas the lowest wind speed occurred after midnight and achieves the minimum at 7 AM to 8 AM. On monthly basis, Kagbeni and Thini have the highest average wind speed in June (being 9.04 -9.75m/s and 7.05 -7.6m/s at 10m and 20m height) whereas Palpa in March and April (3.5 -3.8m/s at 10m and 20m Height). Likewise, the highest wind speed at Kagbeni is found as 22.53m/s and 21.75m/s in April, at Palpa 17.66m/s and

17.11m/s in April, and at Thini 17.9m/s and 17.3m/s in March at 10m and 20m height respectively.

2. On an annual basis, Kagbeni, Palpa, and Thini at 10m have the annual average wind speed of 6.8m/s, 2.65m/s, and 5.59m/s while at 20m height has 7.25m/s, 2.9m/s, and 6.05m/s annual average wind speed. On basis of wind energy potential, Kagbeni has an annual potential energy of 3.98MWhr/m^2 at 10m height and 4.82MWhr/m^2 at 20m height with wind speed greater or equal to 3m/s was about 70% of the total time while Palpa has the potential of 0.27MWhr/m^2 and 0.36MWhr/m^2 at 10m and 20m height with wind speed more or equal to 3.5m/s were about 35% of total time. Similarly, Thini has a potential of 2.4MWhr/m^2 and 2.9MWhr/m^2 at 10m and 20m height with wind speed greater or equal to 3.5m/s at about 60% of total time.The findings of the study show that the two places Kagbeni and Thini show fairly good wind power potential (WPD) for wind energy and are technically feasible for large-scale wind energy production while Palpa shows fair WPD, suitable for small scale wind energy generation.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR'S CONTRIBUTION STATEMENT

D L Yadav: Participated in collecting Wind Data and helped in developing the concept for analyzing it.

S P Gupta & B Adhikari: The Data collected was analyzed and completed the wind power analysis of the three sites of Nepal.

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DATA AND MATERIALS AVAILABILITY

All data associated with this study are received from the Alternative energy Promotion Centre and the Department of Hydrology and Meteorology of Nepal.

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