Pergamon

Renewable Energy, Vol. 14, Nos. 1–4, pp. 441–446, 1998

Printed in Great Britain
0960–1481/98 $19.00+0.00

PII: S0960–1481 (98) 00101–3

POTENTIALS OF WIND ENERGY DEVELOPMENT FOR WATER PUMPING IN JORDAN

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ABSTRACT

The potential of the development of water pumping using wind energy in Jordan was studied. Underground water can be pumped using wind power. Based on available wind data eleven wind sites were considered. The results show that these sites can be divided, in terms of the annual amount of pumped water, into three categories. One is considered "favorable", which includes Ras Muneef, Mafraq, and Aqaba. Their water output adds up to most of water produced from all eleven sites combined (about 64%). Others are considered to be "promising", which include H-5, Irbid, and Ma'an. Their water output adds up to about to 28% of all water pumped at all sites combined. The rest of sites considered are found to be "poor", which include H-4, Amman, Queen Alia's Airport, Shoubak, and Deiralla, with much smaller amounts of water output. Their combined water output adds up to less than 8% of all site combined. © 1998 Elsevier Science Ltd. All rights reserved.

KEY WORDS

wind power, water pumping, Jordan.

INTRODUCTION

Jordan is characterized by an arid to semi-arid climate. Rainy seasons are short and annual rainfall intensities range from 600 mm in the northwest to less than 50 mm in the eastern and southern deserts, which form over 90% of the country's surface area (Bilbeisi, 1992). Groundwater is considered to be the main water resource in most areas, and in some areas it is the only water resource. Water pumping is a basic need for the population in these areas where the national electric grid and water network are not available. Generally, water pumps are driven by diesel engines. In 1985, the first project on the utilization of PV generators instead of diesel engines for water pumping in rural desert was carried out by the Royal Scientific Society (Mahmoud, 1986). In this paper the potential of wind energy development for water pumping is investigated for eleven sites, based on available wind data.

WIND ENERGY IN JORDAN

It is very well established that wind energy resource is large and globally wide spread. For different applications in many locations, it is clear that wind energy can be competitive (Adell *et al.*, 1987, Musgrove, 1987, Pandey and Chandra, 1986, Quraeshi, 1987a, Quraeshi, 1987b). In a recent study, an evaluation of wind energy in Jordan, and its application for electrical power generation was published (Habali *et al.*, 1987). It was found that the monthly average wind speed and wind power density range from 0.7 to 7.2 ms^{-1} and from 2 to 460 Wm^{-2}, respectively. The annual average wind power density was calculated from the measured speeds of eleven stations distributed all over the country. These stations are shown in Fig. 1. They include Amman, Aqaba, Deiralla, H-4, H-5, Irbid, Ma'an, Mafraq, Queen Alia's Airport, Ras Muneef, and Shoubak. Their power outputs vary within the range of 22 to 275 kWm^{-2}.

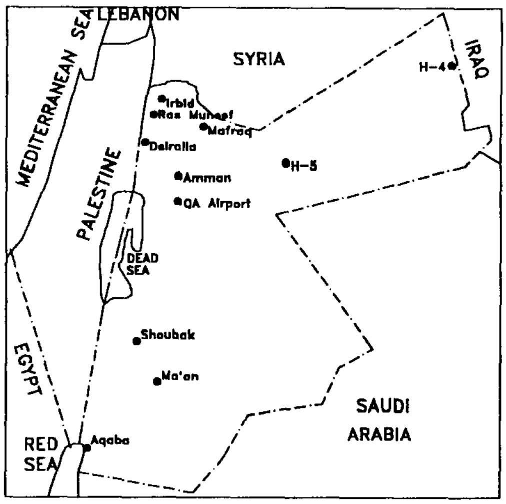

Fig. 1 Map of Jordan with wind sites.

The monthly average wind speeds recorded for the above sites are presented in Fig. 2 and 3. In terms of wind speed Ras Muneef, Mafraq, and Aqaba are the three most potential sites among all sites covered. Their annual average power densities are 275, 270, and 202 Wm^{-2}, respectively (Habali *et al.*, 1987). In a recent study, several wind energy water pumping units were installed in a number of remote arid areas of the Jordanian desert (Anani and Wakileh, 1993). The aim of such projects was to provide people in these locations with drinking underground water.

ENERGY FOR WATER PUMPING

The pumping (or hydraulic) energy required to deliver a volume of water is given by:

$$E_h = \rho_w g V H \tag{1}$$

The input energy for the pumping system undergoes several conversions before it is made available as useful hydraulic energy. The input energy requirements for pumping are generally much greater than the useful hydraulic energy output because of the energy losses associated with each conversion. The power required to lift a given volume of water depends on the time that the pump is used. It is given in the following equation:

$$P_h = \rho_w g Q H \tag{2}$$

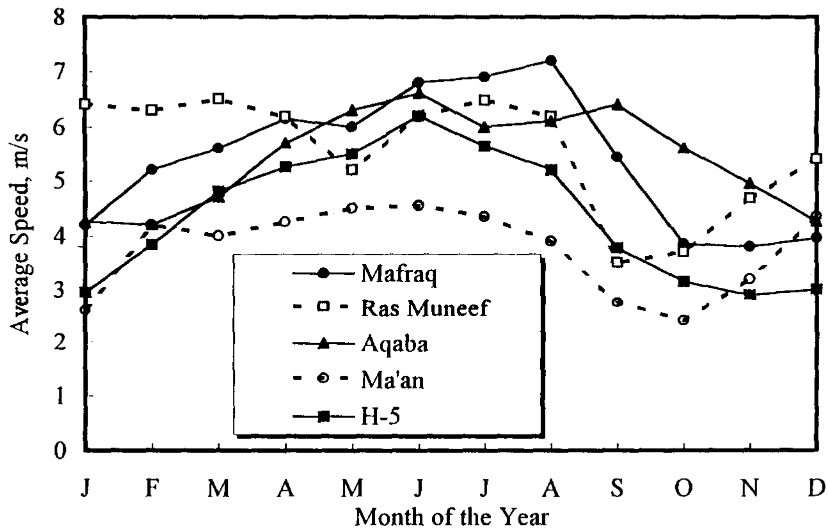

Fig. 2 Monthly average wind speeds for Mafraq, Ras Muneef, Aqaba, Ma'an, and H-5 (Habali *et al.*, 1987).

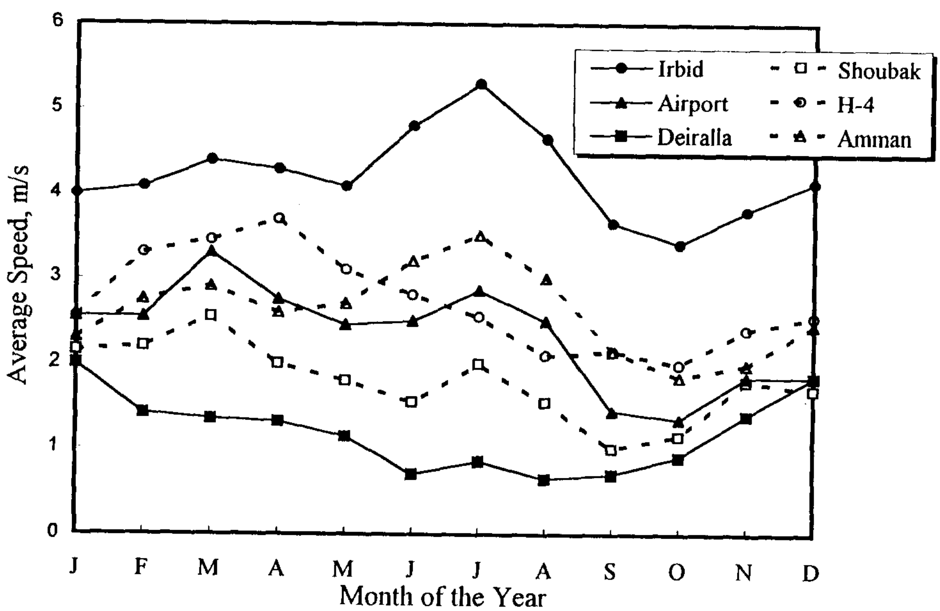

Fig. 3 Monthly average wind speeds for Irbid, Shoubak, Queen Alia Airport, H-4, Deiralla, and Amman (Habali *et al.*, 1987).

The total head comprises the sum of the static head and the head loss in pipes, which depends on the pipe diameter and flow rate. Water pumping system driven by wind energy is proposed. The system is mechanically powered directly coupling the wind energy conversion system (WECS). The available power of the WECS is obtained from the following equation:

$$P_{WECS} = C_p \left[\frac{1}{2} \rho_a A u^3 \right] \tag{3}$$

$$P_h = \eta \, P_{WECS} \tag{4}$$

Substituting eq. (2) and eq. (3) in eq. (4), the following equation can be obtained for the amount of water that can be pumped:

$$Q = \frac{\eta C_p \rho_a A u^3}{2 \rho_w g H} \tag{5}$$

In order to apply the above model, a wind machine was selected. Its characteristics are listed in the Appendix. Figure 4 represents the amount of water that the given pumping unit can provide at different wind speeds and system head heights.

DISCUSSION

The annual amounts of water that can be pumped to a height of 20 m for all wind sites considered are shown in Fig. 5. As presented by the figure, it can be seen that Ras Muneef, Mafraq, and Aqaba represent the most favorable wind sites for water pumping. The annual water output at these three locations can add up to about 64 % of all water produced from all eleven sites combined. Therefore, in terms of water output, the sites can be divided into three different categories; one is considered to be "favorable", that includes Ras Muneef, Mafraq, and Aqaba. The second category is considered to be promising. It includes H-5, Irbid, and Ma'an, H-5, and Irbid. About 28% of the annual water output from all sites combined is obtained at these three locations. These locations are referred to as "promising", so that one may consider other alternatives, such as considering other renewable energy method for water pumping and comparison with wind power.

The third category was considered to be "poor" in terms of water output. That includes the following locations: H-4, Amman, Queen Alia's Airport, Shoubak, and Deiralla. The annual water output at these location was very small; only traces of water can be obtained at the given wind speeds, i.e., less than 8% water is produced at these combined location when compared to water production in all eleven sites. For these locations wind driven pumping system may not be the best choice, other methods should very strongly be considered.

The monthly amounts of water that can be pumped in a year cycle for the four most favorable wind sites are presented in Fig. 6. These locations include Ras Muneef, Mafraq, Aqaba, and H-5. Although, Ras Muneef, Mafraq and Aqaba produced not only the most annual amount of water, but also they were very close to each other; what is interesting to note that one looks more attractive than the other. On one hand 52% of the annual amount of water produced at Ras Muneef takes place during the months December through April. Jordan is characterized as a semi-arid region. These months are considered to be the rainy months by which water consumption is low and may not be needed the most. On the other hand the opposite is true for Mafraq and Aqaba. At Mafraq 57% of annual output of water is during the months of May through August. At this location wind powered pumping system would be an excellent choice, when water consumption is high. Similarly, at Aqaba of which about 61% of water is obtained during the period of May through September.

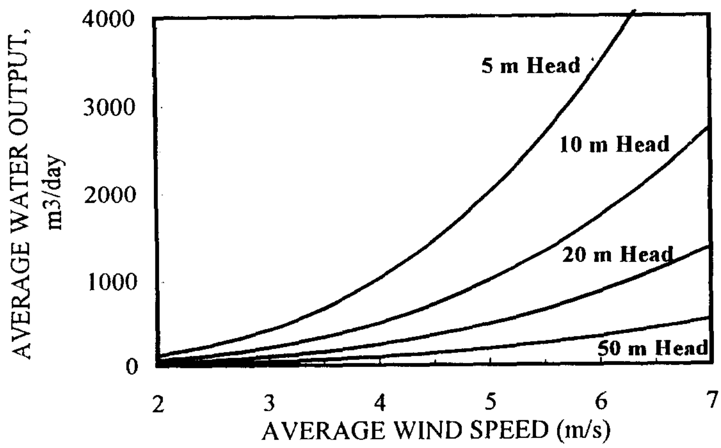

Fig. 4 Water output at different wind speeds and variable heights.

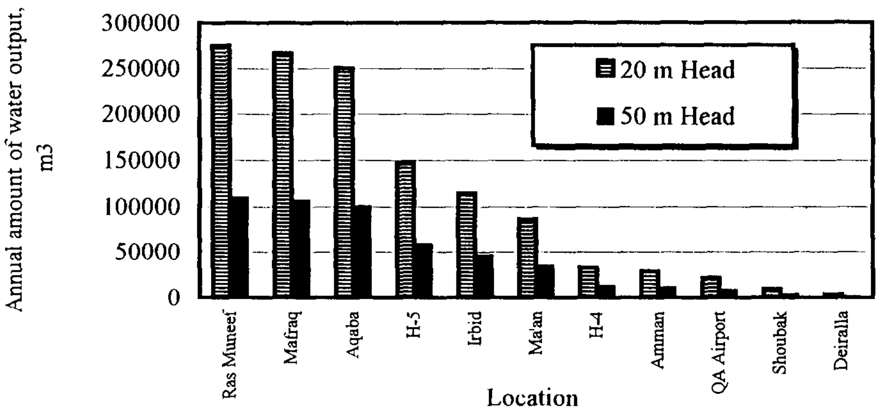

Fig. 5 Annual water output for all wind sites.

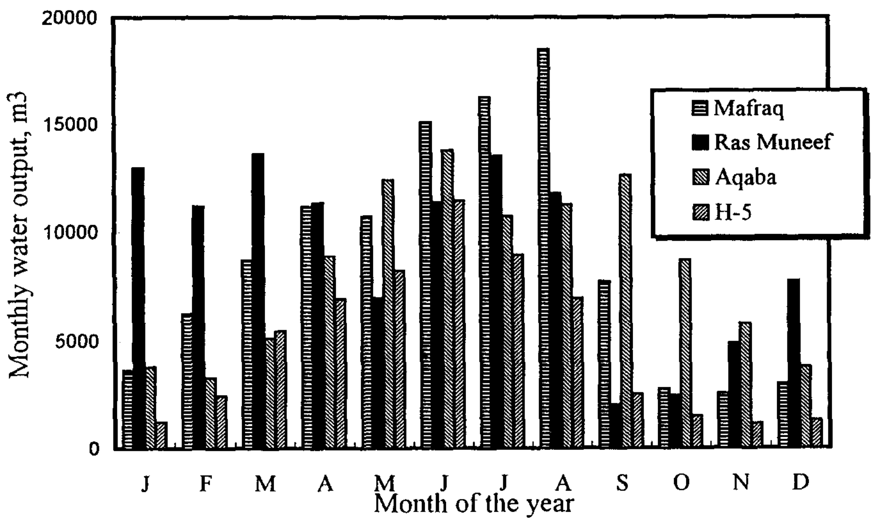

Fig. 6 Monthly water output for Mafraq, Ras Muneef, Aqaba, and H-5.

CONCLUSION

Some wind sites in Jordan show a favorable application towards wind powered water pumping. They include Mafraq, Ras Muneef, and Aqaba. However, H-5, Irbid, and Ma'an have shown to be promising. The rest of wind sites considered, which include H-4, Amman, Queen Alia's Airport, Shoubak, and Deiralla were found to be unattractive in terms of wind powered water pumping.

NOMENCLATURE

- C_p coefficient of power
- E_h pumping (hydraulic) energy required, kW h
- g acceleration due to gravity, m s^{-2}
- H head of water, m
- Q water flow rate m^3 s^{-1}
- P_h pumping (hydraulic) power, kW
- P_{WECS} power output from wind energy conversion system, kW
- u wind speed, m s^{-1}
- V quantity of water produced, m^3
- η efficiency of transmission
- ρ_a air density, kg m^{-3}
- ρ_w water density, kg m^{-3}

APPENDIX

Wind Machine Data:

- Rated Power: 11 kW
- Rotor diameter: 11 m
- ρ_a = 1.22 kg m^{-3}
- ρ_w = 1000 kg m^{-3}
- C_p = 0.35
- η = 0.45
- Operating Wind Speeds:
  —Cut-in = 3.5 m s^{-1}
  —Rated = 8.5 m s^{-1}
  —Cut-out = 24 m s^{-1}
  —Furling = 50 m s^{-1}

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