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Techno-economic analysis of utilizing wind energy for water pumping in some selected communities of Oyo State, Nigeria

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ABSTRACT

This paper presents the technical, economic and environmental benefit of meeting the water requirements of some selected communities in 3 regions of Oyo state, using off-grid wind energy conversion system. The study is conducted using 16 years (2000–2015) daily average wind speed data obtained from Nigeria Meteorological Agency (NIMET), Oshodi, Lagos. The data are observed at anemometer height of 10 m and extrapolated to turbine hub height. The water requirements of the locations are estimated using water consumption data obtained from Nigeria Population Commission (NPC). The wind power analysis of the sites are conducted using 2-parameter Weibull probability distribution to ascertain the wind power potential for water pumping application. The complete system is designed in such a way that the energy requirement of the pumps matches the wind power of the sites. The annualized life cycle cost of the system over 20 years lifetime and the cost per cubic meter of pumped water are evaluated. The results show that the wind power densities of the 3 divisional areas range from 165.75to207.2 W/m^2 and it is sufficient to provide for the water requirements between 1987 m^3/day to 2333 m^3/day) for the areas. It is also revealed that Polaris P50 with rated power of 50 kW, cut-in, rated and cut-out wind speed of 2.7 m/s, 9 m/s and 25 m/s, respectively is the most suitable wind turbine. The water pumps that match the requirement of the sites are identified to be 320 L series Goulds model submersible pumps in the range of 30–50 hp. The annualized life cycle cost of the system ranges from $7,985-$11,594 and the unit cubic cost of pumped water ranges from $0.014–0.025 m^3/day. This paper provides first-hand scientific information to the investors, government officials and policy makers at alleviating the water poverty in Nigerian communities. This would impact positively on the well-being of the local residence.

1. Introduction

The increasing demand for water as a result of population growth is exerting pressures on water resources in recent time. This is also making the existing infrastructure for water provision to operate at its limit [1]. Provision of safe and adequate water for consumption will continue to be an important issue particularly in the less developed countries because of their peculiar water related health challenges compared to other developed nations. Most of the water crises experienced around the world have been attributed to unstable and unsustainable water policies and not as a result of total lack of water resources [2,3]. According to World Health Organization, almost two-fifths of the world population do not have access to adequate sanitation and 768 million people do not have access to safe water [4]. Around 700,000 children which amount to 2000 children per day die from diarrhea caused by unsafe water and poor sanitation [5].

In Africa, the demand for water has been on the increase in recent years [6] and has been attributed to a number of factors. Some of these factors include: increase in population, rising agricultural demand [7], rapid urbanization and frequent droughts in some regions of the continent. Lack of access to potable water has been identified as one of the problems in African community that can induce communal conflicts [8] as a result of people migrating from their communities in search of the scarce resources.

In Nigeria, one of the fundamental problems is lack of access to safe sources of water supply.

Nigeria's water infrastructure has suffered from severe neglect as a result of high population growth which results in an ever increasing demand for water and sanitation services against a diminishing trend in its supply thus creating a large supply gap. Rural areas in particular have been neglected from water services and majority of people living in urban areas are forced to buy water from private vendors, which most cannot afford. This accounts for low quality of water consumption with its associated health issues. This is one of the reasons, the provision of water continue to reflect in the political campaign in the country. Low investment level in operation and maintenance accounts

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for frequent break down of distribution facilities. The inadequate electric power supply for water pumping also contributes to high rate of water poverty in the country.

Due to the challenges associated with lack of access to potable water and the concerns of energy shortage in the country, the use of renewable energy resources as an alternative energy source are beginning to gain increasing attention. The use of photovoltaic water pumping systems has recently received good consideration especially in areas where solar energy is abundant and in remote areas where grid power is either not feasible or non-existing [9,10]. In this work, the authors are motivated by the level of increasing utilization of solar-powered water pumping system and are of the opinion that similar attention could be given to wind energy for water pumping if its advantages are also well understood. In this paper, the level of water poverty in some selected locations of Oyo state, Nigeria is first ascertained and the water requirements of the locations are determined. These locations (consisting of 14 communities) are selected because of the prevalence of water poverty in the area and the ease of access to data needed for the study. Thereafter, assessments of the wind regime of the locations are performed to determine their suitability for water pumping application. The appropriate wind turbines are then matched with the suitable water pump based on the characteristic of the local wind regimes of the locations. This paper is important because it could serve as first-hand scientific information to the investors, government officials, policy makers and engineers at improving the water poverty in local communities. This would indirectly impact positively on the health and well-being of the local residence.

2. Experimental data

The study is focused on 3 divisional areas of Oyo state which are Ibadan, Iseyin and Saki. There are 11 locations in Ibadan division (denoted by L_1-L_{11}), Iseyin division consists of only one location (L_{13}) while Saki division has 2 locations (L_{13} and L_{14}) as depicted in Table 1. In this study, the locations that fall into the same divisional area are assumed to have similar wind speed characteristics. For example, the 11 locations in Ibadan division have similar wind speed characteristics. This is because they have similar geographical feature. The locations within the same divisional areas are depicted in Fig. 1.

The water requirement of each location was determined based on the data collected from Nigeria Population Commission (NPC), Ibadan. The modified summary of the data is as depicted in Table 2.

The study was conducted using 16 years (2000–2015) daily average wind speed data obtained from Nigeria Meteorological Agency (NIMET) located in Oshodi, Lagos. A mast was located at each of the divisional area i.e. a mast was erected at Ibadan, Saki and Iseyin as depicted in Fig. 1. The installed anemometer measures daily average wind speed sampled at 0.5 Hz at anemometer height of 10 m with cup anemometers

Table 1
Classification of locations within divisional areas.

Division	Designation	Locations
Ibadan	L_1	Ibadan North East
	L_2	Ibadan North
	L_3	Ibadan North West
	L_4	Ibadan South East
	L_5	Ibadan South West
	L_6	Ido
	L_7	Lagelu
	L_8	Oluyole
	L_9	Ona Ara
	L_{10}	Akinyele
	L_{11}	Egbeda
Iseyin	L_{12}	Iseyin
Saki	L_{13}	Saki East
	L_{14}	Saki West

(model P2546). All the masts are installed in an open area indicating that the wind speeds are free from nearby obstructions such as mountains and buildings.

The parametric values of these stations consisting of the periods of data collection, average wind speed, the altitude above sea level, the geographical location (latitude and longitude) as well as the standard deviation of the wind speed data are furnished in Table 3.

3. Water poverty in Oyo State

In this study, the household are classified into two: the household with access to adequate and safe water and the one short of adequate and potable water. We define the household with access to safe water as those households that have access to the following water sources: pipe borne water right inside their home (PI), pipe borne water right outside their house (PO), access to water through water tanker supply (TS), access to well supply and borehole (BH). Conversely, we considered the population of household that depend on the following water sources as being water poor: household that depend on rain water (RW), those that depend on river, stream or spring water (RSS), households that depend on pond, lake or dam (PLDP) and those that depend on any other sources apart from the one mentioned (OT). Based on the classification of water sources in Table 3, the percentage of household with potable water and that of limited access to adequate and potable water are calculated and the result is furnished in Table 4.

From the table it is observed that Saki East (L13) has the highest "water poverty" followed by Ido (L_6), Iseyin (L_{12}) and Lagelu (L_7). This is because these locations are far from the state capital where tanker or the water distribution infrastructure can easily be reached. Moreover, most of the resident of these locations can hardly afford borehole or well to complement their water requirements. Hence they predominantly depend on rainwater and water from stream or spring which are seasonal [11]. Some of these water sources dry up during the dry season living the resident wondering about for water. In some household, the children miss school in search of water for domestic use. Moreover, most of the sources are polluted from different human activities [12] majorly through bush burning, use of fertilizer and pesticides, herbicides, fungicides and others which cause soil runoff into surface water thereby making the water unfit for drinking. This results into the prevalence rate of water borne related health issues [13]. Therefore, this paper examines the feasibility and viability of utilizing wind power for water pumping in some selected location of Oyo state and then determines the technical andeconomic benefit of adopting wind-powered water pumping technology.

4. Wind powered water pumping system

Wind-powered water pumping system comprises of wind turbines, pump, battery bank, converter, inverter and battery charging controller. The wind turbine supplies intermittent energy as a result of incessant change in wind speed. This is mitigated with the use of battery bank system which serves as storage that stores the wind energy. The converter converts the AC wind turbine output to DC. The charging of the battery bank is monitored by a charge controller that ensures efficient charging of the battery through overcharging and undercharging monitoring control. The inverter revert the direct current obtained from the battery to a sinusoidal waveform needed by the centrifugal pump to lift water to the storage tank. The storage tank is useful to serve as a temporary hold of water in times when wind turbine cannot generate or battery bank energy is low. The system block is represented in Fig. 2.

5. Wind power assessment of the locations

The assessment of the wind power of the locations is of vital relevance to determine the available wind power that can be harnessed