INTRODUCTION

Eastern India comprises mainly the states of Assam, Bihar, Chhattisgarh, Jharkhand, Odessa, Eastern Uttar Pradesh and West Bengal with geographical area of 71.84 million ha and human population of 520 million (Planning Commission, 2012). This region has the distinction for its fertile land, excellent environment and vast potential of groundwater reserve. However, the food production and productivity of this region is often been risky and relatively of low return due to erratic rainfall and lack of assured irrigation (Lobell et al., 2001; Held et al., 2005). To save the crops from long dry spells, farmers are solely dependent on groundwater for supplementary irrigation. The intensity of groundwater utilization in this region is quite apparent from the fact that there are about 5.09 million pumps of which 84% (4.28 million) are of diesel pumps with average annual duration of operation per pump 462 hours (Shah, 2009). In absences of grid electricity farmers are forced to use diesel pumps irrespective of their land holding sizes. In general, they use 5 horsepower pump which consumes nearly 1.15 liters of TMT diesel per hour. As one litre of diesel generate carbon emission of 0.732 kg (Nelson and Robertson, 2008), therefore, total annual emission of carbon by 4.28 million diesel pumps alone be 1.67 million tons! In coming decades the numbers of pumping hours are bound to increase due to climate change and widened uncertainty in rainfall (Haris, et al., 2013; Raha and Mishra, 2013; Dash, 2011). This will further accelerate the diesel consumption and therefore the carbon emission. Eastern region of India is blessed with immense solar energy potential of 6.4 - 4.3 kWh/m²/day with 250 - 300 clear sunny days per year, which could be year round reliable source of energy for groundwater pumping (Sharma et al., 2012; Ramachandra, 2011, Jaswal, 2009). Further, the farmers are traditionally performing surface method of irrigation which led overexploitation of groundwater. Therefore, the use of pressurised irrigation technologies could be an additional water management strategy for optimizing groundwater use (Hillel, 1989; Keller et al., 2001). The solar powered groundwater pumping coupled with pressurised irrigation systems could be an appropriate alternative approach for minimizing diesel consumption, judicious exploitation and use of groundwater, reducing carbon emission, improving water and fertilizer use efficiency and increasing crop yield (Qureshi et al., 2001; Sivanappan, 2002; Namara et al., 2005, Narayananamoorthy, 1997; Dhawan, 2000). Since, the different crops have different water requirements and these requirements fluctuate with crop growth, therefore, the proper choice of crop successions and combinations are of decisive importance in sizing of solar pumps. Uninterrupted crop rotation or continuous cropping systems with high value added crops such as fruit, vegetables and spices are to be grown to reduce the payback time of solar system. However, for effective implementation of this technology, an appropriate groundwater pumping unit along with delivery system is to be devised and tested in this region which could be referred for further designing, installation and optimization of solar pumps.

KEY WORDS
Energy
Irrigation
Solar radiation
Groundwater
Eastern India

ABSTRACT

Groundwater abstraction to meet irrigation demand is becoming difficult affair due to significant energy poverty and pervasive electricity deficits in Eastern India. In this scenario solar powered groundwater pumping could be the most viable and sustainable option in view of solar energy potential of this region. The spectrum of solar energy is quite wide and its intensity varies according to the timing of the day and geographic location. However, as an evolving technology its feasibility in groundwater pumping is to be assessed in view of solar radiation intensity and groundwater depth scenarios. In this paper we developed and evaluated a solar powered ground water pumping system installed at Patna (25.65°N). This system can abstract groundwater of 104 - 174 m³ per day which is enough to irrigate 2000-3000 m² cropped area per day even by surface method of irrigation. This system also offers a pressure head, ranging between 1.0 - 1.4 bars from 9.00 hrs to 14.30 hrs and therefore system can drive pressurised irrigation successfully. Further, the evaluation of power output of a 3000Wp solar array under the solar energy intensity of Eastern region showed that, for operating one horsepower pump the driving solar array size should be of 1000Wp to operate the pump at full capacity for at least for 5 hours on a bright sunshine day round the year.
powered groundwater pumping system, especially for irrigating small to medium land sizes, in view of seasonal variation of incident solar radiation and ground water level fluctuation. This paper describes a solar photovoltaic ground water pumping system, designed and tested at Patna (25.65°N) to fulfil these prepositions.

**MATERIALS AND METHODS**

In solar photovoltaic water pumping, generally two different system configurations are employed. In first configuration, solar photovoltaic electricity drives a surface or a submersible pump to lift groundwater and injected directly into the irrigation system without any storage system. In other configuration, solar photovoltaic electricity drives a surface or a submersible pump to lift ground water into an overhead tank. This tank serves as an energy store and supplies the pressure needed for pressurised irrigation system. Another configuration, as been devised in this paper, the solar photovoltaic electricity drives an ac submersible pump to lift ground water into a grounded tank and a surface dc pump delivers water out of tank to the fields for irrigation. As, the groundwater pumping unit is decoupled with water delivery unit, the drafted groundwater per day is high due to reduction in total head of the pump. This sort of configuration enables the user to lift more groundwater even from a deeper depth. Further, as the delivery pump is extracting water out of a grounded storage tank, therefore it encounters a very low suction head and hence delivery head is automatically high. Therefore, with this system, irrigation can be performed by surface or by pressurised methods of irrigation by coupling delivery pump directly with irrigation network. In addition to this, high delivery head also enables the users to carry irrigation water to distant fields. Further, as both the pumps can be operated in tandem, therefore, the storage tank could serve as reservoir for fish and duck farming.

The developed photovoltaic groundwater pumping system is shown in Fig. 1. The attributes of solar arrays, pump, accessories along with costs are reported in Table 1. A 3000Wp solar array energizes a 3hp submersible ac pump of rated power of 2.2 kW for groundwater pumping positioned at 20 m below the ground level. The positioning depth of the pump was selected in view of groundwater depth scenario in Eastern region. Where, in general, water depth below the ground level is ranging from 2 - 10 m with annual fluctuations of ±2 to ±4 m in pre and post monsoon barring few pockets (GWYB, 2012). This region receives maximum global solar radiation of 6.4 kWh/m²/day in the month of April and minimum of 3.5 kWh/m²/day in the month of December. The diurnal variation of solar radiation intensity of the experimental site on a bright sunshine day, measured by solar pyranometer installed at the site, for different months is shown in Fig. 2.

As the solar modules give only dc output, therefore, to operate ac pump, a Variable Frequency Drive (VFD) along with Maximum Power Point Tracker (MPPT) were used. The groundwater was pumped into a grounded tank of size 9.75

### Table 1: Cost of the solar system including pumps, accessories and cemented tank

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Items</th>
<th>Unit</th>
<th>Rate(US$)/unit</th>
<th>Cost(US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solar arrays</td>
<td>4500 Wp</td>
<td>1.2/Wp</td>
<td>5364</td>
</tr>
<tr>
<td>2</td>
<td>Tracking structure</td>
<td>4</td>
<td>345</td>
<td>1380</td>
</tr>
<tr>
<td>3</td>
<td>3HP AC submersible pump</td>
<td>1</td>
<td>430</td>
<td>430</td>
</tr>
<tr>
<td>4</td>
<td>2HP DC centrifugal pump</td>
<td>1</td>
<td>1125</td>
<td>1125</td>
</tr>
<tr>
<td>5</td>
<td>VFD + MPPT</td>
<td>1</td>
<td>860</td>
<td>860</td>
</tr>
<tr>
<td>6</td>
<td>PCC Tank (9.75m×4.8m ×2.5m)</td>
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<td>2585</td>
<td>2585</td>
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<tr>
<td>7</td>
<td>Accessories</td>
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<td>175</td>
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</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td><strong>11955 US$</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Site view of solar photovoltaic groundwater pumping system

Figure 2: Diagram, showing the mean monthly diurnal variation of solar irradiance, received on cloud free day at Patna (25.65°N).
m × 4.8 m × 2.5 m. An additional dc centrifugal pump of 2 hp was used to deliver water from tank to the fields for irrigation. This pump was powered by solar array of 1500Wp. For both the pumps, solar panels were mounted on a dual-axis passive sun tracking structures which provided 13-21% more water, depending upon seasons, compared to the fixed panels with tilt angle equal to the local latitude as recommended in literatures (Kern, 1975; Iqbal, 1979; Ahmed and Tiwari, 2009).

RESULTS AND DISCUSSION

The solar radiation intensity obviously varied with change in daytime and so the discharge of the solar powered pump due to change in input power. Therefore, instead of measuring instantaneous discharge, the measurement of average discharge of the submersible pump was more relevant. As per the affinity law of capacity and pump speed (Jones, 2008), the discharge of the pump is proportional to the speed (rpm) of the pump. Therefore, the rate of discharge of the pump at any point of time was measured by developing a relationship between the rate of discharge \( d \) and driving frequency \( f \) of the pump, recorded from VFD. The discharge vs. driving frequency plot showed that the two parameters were linearly related as \( d = 0.2734 f - 6.3496 \) with \( r^2 = 0.998 \). To estimate the total volumetric discharge over a day the \( f \) values were recorded from the VFD screen at every 15 minute interval.

The total volumetric discharge of the pump for 15 minute interval was calculated by putting the mean value of \( f \) of two extremities of this interval into the above mathematical relationship to work out the discharge and the multiplied by time period of 15 minute. The cumulative value of each of this interval over whole day gave the total volumetric discharge per day. The estimated result was further authenticated by measuring the water volume in the tank. It was observed that there was only a \( \pm 5\% \) difference in estimated and measured values. In this way the net drafted groundwater for bright sunshine days were calculated for different months.

The mean monthly daily water output along with global solar radiation for different months on bright sunshine day, and the depth of water below ground level are depicted in Fig. 3 and Fig. 4, respectively. Interpretation of Fig. 3 showed that, in the month of April, on a bright sunshine day, the net drafted groundwater per day was 174m³, whereas in the month of December it...
was 104 m³ per day. In other months water output per day was lie between these two values. Variation in daily water output in different months could be attributed to the change in day length, difference in global solar radiation and water depth below ground level. In general, the field crop irrigation by surface method, the required depth of water per irrigation is nearly 5.0 cm (Singh, 2009). Therefore, this system is capable to irrigate 2000 - 3000 m² field crops per day by surface method of irrigation.

The static delivery head vs. discharge and static delivery head vs. irradiance of the delivery pump is shown in Fig. 5 and Fig. 6, respectively. Interpretation of these two figures showed that the pump could withstand a pressure head of 10 - 14 m when solar irradiance ranged from 650-900 W/m². This irradiance condition prevails in the months of March to October on a bright sunshine day. However, in low solar insolation months (November to January), between 9.30 - 14.00 hrs the solar irradiance ranged from 450-650 W/m² during which delivery pump can withstand the pressure head of 8 - 10 m. These characteristics of delivery pump shows that it can withstand 0.8-1.4 bars of pressure round the year on every bright sunshine day between 9.30 to 14.30 hrs. Therefore, this pump can operate most of the available dripper and mini-sprinklers by coupling it directly with the pipe network as these are requiring operating pressure of 1.0 bar for successful operation (Phocaides, 2000; Kyada and Munjapara, 2013).

Further, the evaluation of power rating of solar array for a given solar irradiance condition in different month is important for sizing of solar array for a given pump capacity. For this, the power rating of a solar array of 3000Wp was measured in terms of product of the current and voltage output of the array as done in other literature (Aja, et al., 2013). This was estimated on bright sunshine days in different months by mounting the solar array on manual sun tracking structure. The results obtained from the experiment shown in the Fig. 7. Interpretation of the plot indicates that, between 9.30 hrs to 14.30 hrs, the rated power of the array was in the range of 1.8 - 2.5 kW. This shows that, with 3000Wp solar array a 3 hp pump can be operated at least for 5 hrs nearly at its factory rated power. Hence, for solar powered ground water pumping system for eastern region of India it is desirable to use 1000Wp array for operating one horsepower pump. The cost of the system including accessories and cement tank are reported in Table 1.

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REFERENCES


