



## Development and performance evaluation of a water lifting device

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Although access to water is not the only factor that affects agriculture, improving water control for small-scale agriculture may be the main choice to ensure smallholder production (Burney and Naylor 2012). Pumped irrigation is dominated by electricity and diesel systems worldwide. Due to the continuous use of electricity from the grid and expensive fuels, farmers bear high operating and maintenance costs. Again, they are closely associated with air pollution due to toxic gas emissions and noise (Chandel *et al.* 2015, Aliyu *et al.* 2018). Access to adequate water has a considerable impact on socio-economic development and quality of life (Baumann and ERPF 2005). It is very difficult to design a water lifting device which has good performance, easy maintenance and low cost. In spite of improvements in design, a suitable pump that will be operating with minimum effort having low maintenance needs to be developed. Therefore, the present study aims to meet a specific part of this demand, thereby making a positive contribution to the quality of life and living standards of human beings, especially in rural areas. Generally, pumps require a lot of energy and effort to pump out the required volume of water (Okoronkwo *et al.* 2016). The various water pumping systems available require a sufficiently large effort of about 36 J depending on the manufacturer to be operated and an average person can use these pumps continuously only for a short time. Whenever a pump is operated by human or animals, it costs cheaper. Water lifting devices operated by humans and animals have traditionally been used for irrigation in many parts of the world. Now, attention is given towards efficiency improvement and higher output, i.e. release of water. The physical power of human lies between 0.08–0.10 hp, and that of animal is approximately 5–10 times more. For e.g. the physical strength of a pair of bulls is about 0.8 hp and can lift water from a depth of 30 m or more. Therefore, animals are competent to pump

extra water in small time, thereby productivity and irrigation efficiency are increased.

In the past, a number of devices have been developed which are ancient and traditional and it has been observed that most of these devices are simple in structure, and could be made from local resources, low cost, easy to use with low maintenance. But, these devices are large in sizes and intricate shape. Again, these are suitable for low to medium discharge with moderate head, hence efficiency is also below the expected range. A hand water pump was designed using a quick-return crank mechanism to operate by reciprocating movement of the handle. Results show that the mechanism has a capacity of 15.2 litre/min with an effort of 102.7 N, whereas the conventional lever lift mechanism has a capacity of 10.65 litre/min with an effort of 127 N (Okoronkwo *et al.* 2016). Analysis of the mark II pumps by Aderibigbe and Fei (1987) showed that although the India mark II pump is very convenient to design and produce, the pump is very difficult to maintain; if there is a problem in the pumping mechanism, the riser pipes must be removed, resulting in delayed water supply. A pendulum pump was developed for pumping of water to replace hand pumps. This was a simple pump, when compared to traditional hand water pump (Rony *et al.* 2015). A hand operated water lifting device was developed. The equipment was unsuitable for continuous operation for more than two hours. The gear ratio was insufficient to reduce the effort during the operation. Design of linkage mechanism of pedal operated water lifter needed special attention. Because of larger size, it becomes difficult to carry. Hence, foldable mechanism is needed for ease of transportation. Hence, there was a need to develop a cost-effective surface water lifting device with improved features, less maintenance cost and suitable for small and marginal farmers that requires only one person to operate with less effort. So, it was needed to develop a manually operated device to lift a considerable amount of surface water with minimum effort.

In this study, three prototypes were designed and developed at Central Mechanical Engineering Research Institute in Durgapur, West Bengal during 2021.

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The technical specifications of the developed prototypes are given in Table 1.

*Difference between developed prototypes:* Three developed prototypes have been designated as Prototype-I, II and III (Fig 1). The basic differences amongst the prototypes are overall dimension, gear ratio and dead weight. The prototype-I is not having options for folding however, II and III can be folded as and when required for ease of carrying.

*Design of experiments:* To conduct the experiments, three parameters with three levels for each were considered (Table 2). To reduce the number of experiments, Taguchi method was considered. The arrays were selected by the number of parameters (variables) and the number of levels (states).  $L_9$  orthogonal arrays have been considered in this study.

*Performance evaluation:* Initially, experiments were conducted on these developed prototypes to measure the discharge taking average head as 0.5 m. It was observed that the highest discharge was 30 m<sup>3</sup>/hr for prototype-III followed by 28 m<sup>3</sup>/hr in case of prototype-II and 23 m<sup>3</sup>/hr for prototype-I. By taking these three discharge values, two other parameters, viz. total head and input effort were selected for statistical analysis. Thus using these three variables and three levels parameter of each, nine numbers of experiments were conducted to calculate the mechanical efficiency of the developed prototypes (Table 3). Governing equations are as follows:

$$\text{Water horse power (WHP)} = \frac{Q \times g \times H}{3600} \text{ kW (Vesilind et al. 1994)}$$

Where  $Q$ , pump flow rate, (m<sup>3</sup>/hr);  $g$ , gravitational acceleration;  $H$ , total head;

$$\text{Mechanical efficiency, } \eta = \frac{\text{WHP}}{\text{BHP}}$$

Where BHP, Brake horse power; Input power, human effort (taken as 90 W for 20 years old human; 75 W for 35 years old and 60 W for 60 years old for 180 min duration). Taking the mechanical efficiency of the selected chain-sprocket mechanism as 85%, BHP has been calculated.

Table 1 Technical specifications

| Description         | Prototype-I    | Prototype-II | Prototype-III |
|---------------------|----------------|--------------|---------------|
| Overall size (mm)   | 400×260×1060   | 400×270×780  | 400×270×780   |
| Gear ratio          | 1:2            | 1:5          | 1:6           |
| Machine weight (kg) | 12.75          | 13.0         | 13.2          |
| Installation        | Immersed       | Immersed     | Immersed      |
| Portability         | Single machine | Foldable     | Foldable      |

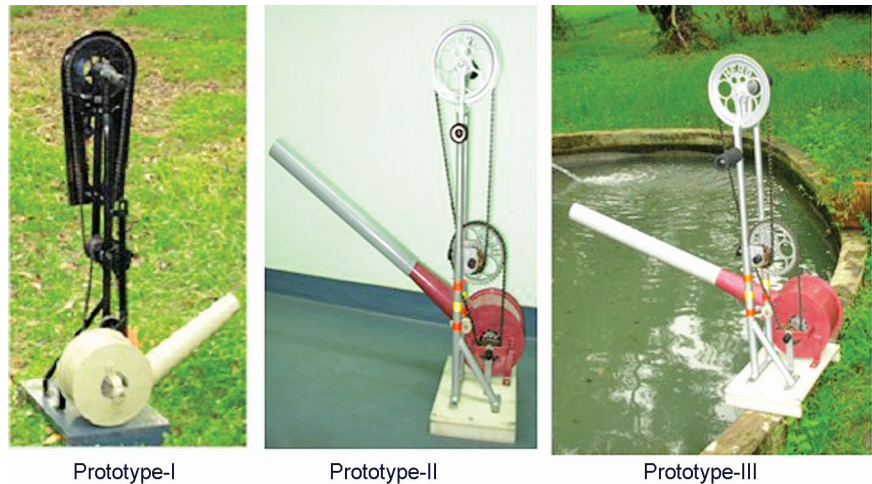


Fig 1 Developed prototypes.

*Analyzing experimental data:* Once the experimental design has been determined, the measured performance characteristics from each trial were used to analyze the relative effect of the different parameters. It should be noted that the Taguchi method allows the use of a noise matrix including external factors affecting the process outcome. To determine the effect, each variable has on the output, the signal-to-noise (SN) ratio has been calculated for each conducted experiment. The calculation of the SN for the first experiment in the array above is shown below for the case of a specific target value of the performance characteristic. In this case, aim was for maximum efficiency of the water lifting device; hence the following definition of the SN ratio was calculated as:

$$SN_i = -10 \log \left[ \frac{1}{N_i} \sum_{u=1}^{N_i} \frac{1}{y_u^2} \right]$$

Table 2 Details of parameters and their levels

| Parameter                                | Level |      |      |
|------------------------------------------|-------|------|------|
|                                          | 1     | 2    | 3    |
| Pump flow rate, $Q$ (m <sup>3</sup> /hr) | 23    | 28   | 30   |
| Total head, $H$ (m)                      | 0.50  | 0.53 | 0.56 |
| Avg. input effort, $E$ (W)               | 60    | 75   | 90   |
| <i>Designs of experiments</i>            |       |      |      |
| Experiment no.                           | $Q$   | $H$  | $E$  |
| 1.                                       | 23    | 0.50 | 60   |
| 2.                                       | 23    | 0.53 | 75   |
| 3.                                       | 23    | 0.56 | 90   |
| 4.                                       | 28    | 0.50 | 75   |
| 5.                                       | 28    | 0.53 | 90   |
| 6.                                       | 28    | 0.56 | 60   |
| 7.                                       | 30    | 0.50 | 90   |
| 8.                                       | 30    | 0.53 | 75   |
| 9.                                       | 30    | 0.56 | 60   |

$Q$ , Pump flow rate (m<sup>3</sup>/hr);  $H$ , Total head (m); and  $E$ , Avg. input effort (W).

Table 3 Details of results for SN ratio and response

| Expt. no. | Q<br>(m <sup>3</sup> /hr) | H<br>(m) | E<br>(W) | WHP<br>(kW) | BHP<br>(kW) | Efficiency<br>(%) | SN ratio |
|-----------|---------------------------|----------|----------|-------------|-------------|-------------------|----------|
| 1         | 23.0                      | 0.50     | 60       | 51.00       | 31.3375     | 61.45             | 35.77    |
| 2         | 23.0                      | 0.53     | 75       | 63.75       | 33.21775    | 52.11             | 34.34    |
| 3         | 23.0                      | 0.56     | 90       | 76.50       | 35.098      | 45.88             | 33.23    |
| 4         | 28.0                      | 0.50     | 75       | 63.75       | 38.15       | 59.84             | 35.54    |
| 5         | 28.0                      | 0.53     | 90       | 76.50       | 40.439      | 52.86             | 34.46    |
| 6         | 28.0                      | 0.56     | 60       | 51.00       | 42.728      | 83.78             | 38.46    |
| 7         | 30.0                      | 0.50     | 90       | 76.50       | 40.875      | 53.43             | 34.56    |
| 8         | 30.0                      | 0.53     | 75       | 63.75       | 43.3275     | 67.96             | 36.65    |
| 9         | 30.0                      | 0.56     | 60       | 51.00       | 45.78       | 89.76             | 39.06    |

*Response table*

| Level | Q      | H     | E     |
|-------|--------|-------|-------|
| 1     | 34.446 | 35.29 | 37.76 |
| 2     | 36.155 | 35.15 | 35.51 |
| 3     | 36.754 | 36.91 | 34.08 |
| Delta | 2.308  | 1.76  | 3.68  |
| Rank  | 2      | 3     | 1     |

*Final experimental results*

| Description                            | Prototype-I | Prototype-II | Prototype-III |
|----------------------------------------|-------------|--------------|---------------|
| Total head (H), m                      | 0.5         | 0.5          | 0.5           |
| Pump flow rate (Q), m <sup>3</sup> /hr | 23          | 28           | 30            |
| Avg. input effort, W                   | 60          | 60           | 60            |
| BHP, W                                 | 31          | 38.15        | 41            |
| Mechanical efficiency(η), %            | 61          | 75           | 80            |

Q, Pump Flow rate (m<sup>3</sup>/hr); H, Total Head (m); E, Avg. input effort (W); WHP, Water horse power; BHP, Brake horse power; and SN, signal-to-noise ratio.

Where  $i$ , the experimental number;  $u$ , the trial number; and  $N_i$ , the number of trials for experiment  $i$ . After calculating the SN ratio for each experiment, the average SN value is calculated (Table 3). Once these SN ratio values are calculated for each factor and level, they are tabulated and the range  $R$  ( $R = \text{high SN} - \text{low SN}$ ) of the SN is calculated. The larger the  $R$  value for a parameter, the larger the effect the variable has on the process. It can be seen that input effort has the largest effect on the efficiency and that head has the smallest effect on the efficiency.

Final experiments were conducted with predefined head and flow rate to calculate the mechanical efficiency (Table 3). The average input effort was considered as 60 W. From the above results (Fig 3), it is observed that highest flow rate as well as efficiency is achieved in prototype-III. But in all cases, the performance is much better than the previously developed device. The efficiency ranges between 60–80% which is quite acceptable for a hand operative water lifting device. The performance was evaluated to calculate mechanical efficiency which comes as 61%, 75% and 80% for prototypes I, II and III respectively. During the testing of these prototypes, it was found that efficiency increases with an increase in gear ratio at the constant head.

## SUMMARY

The uninterrupted availability and price of electric power is a great solicitude for a common man; thus, irregular power availability for irrigation is a daily problem faced by rural farmers. In most rural communities, hand-operated water pumps are very predominant due to lack of electricity to power borehole water systems. Conventional energy is also a great concern and now, core attention of the people is being diverted towards the use of an alternate form of energy derived from human and animals. The need for water as a basic necessity in life has led to various developmental and engineering innovations that are designed to meet this need optimally. The water pump is the most useful machine, and it is the second most commonly used equipment by the farmers for irrigation purposes. An appropriate alternative to diesel pump, which requires neither diesel nor electricity, yet meets irrigation requirements, may be beneficial. With this, a simple hand-operated water-lifting device has been developed at CSIR-Central Mechanical Engineering Research Institute at Durgapur, West Bengal. Three prototypes were developed and evaluated successfully. From the results, it has been observed that, input effort has

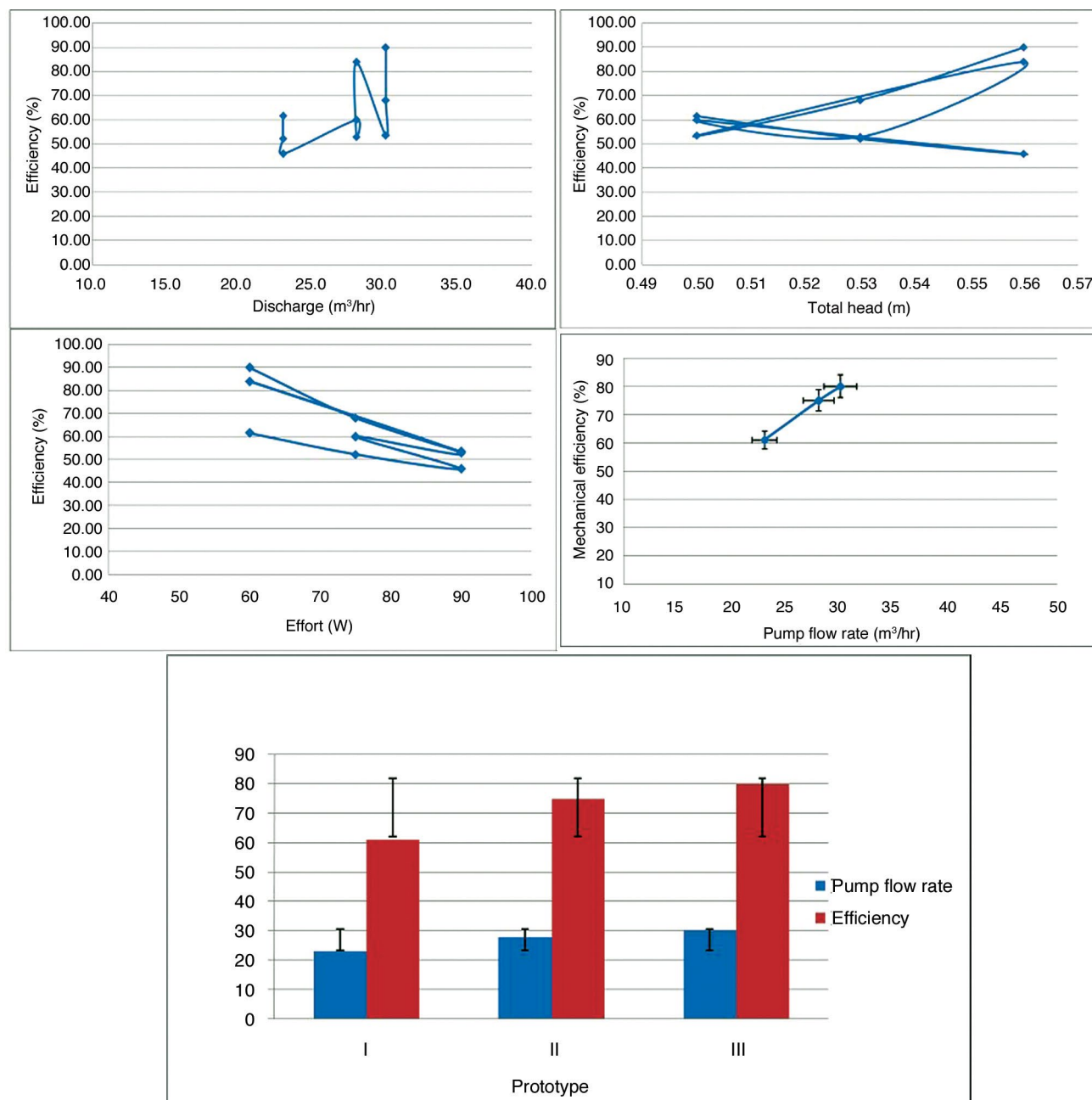


Fig 3 Experimental results showing mechanical efficiency for three prototypes.

the largest effect on efficiency. The highest efficiency was found as 80% in case of prototype-III.

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