

Participatory On-Farm Evaluation of the Hydraulic Performance, Operating Head, Energy-Free Operation, and Farmer Perception of a Locally Developed Spiral Water Pump for Small-Scale Irrigation in Jimma Zone, Southwestern Ethiopia

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ABSTRACT

This study evaluated the hydraulic performance and farmer perception of a locally developed spiral water pump under different pumping heads. Discharge, rotational speed, and efficiency were assessed as head increased from 2 m to 12 m, and farmer feedback was collected on practical operation, maintenance, and perceived benefits. The source results show that discharge and rotational speed decreased as pumping head increased. Discharge declined from 0.25 L s⁻¹ at 2 m head to 0.06 L s⁻¹ at 12 m head, while the reported efficiency also decreased with increasing head. Farmer feedback emphasized fuel-free operation, low operational requirements, and ease of use. The findings indicate that the evaluated pump is more appropriate for low-head applications and for irrigation systems in which water can be stored in a reservoir before application. Further field evaluation should focus on hydraulic optimization, installation stability, and long-term user performance.

Keywords: Spiral Water Pump; Low-Head Irrigation; Water Wheel; Discharge; Pumping Head; Rotational Speed; Hydraulic Efficiency; Farmer Perception; Small-Scale Irrigation; Renewable Energy; Fuel-Free Pumping; Sustainable Agriculture.

1.0. Introduction

The main occupation in rural areas is farming, and numerous groups are attempting to increase crop yields by using more effective irrigation methods. It has been demonstrated that dependable irrigation systems can boost agricultural yields by 100% to 400%, increasing farmers' sales and profits. Farmers may now grow more valuable crops, implement new technology, and improve profits thanks to this growth. Notwithstanding the advantages of irrigation, the high expense of purchasing commercial irrigation technology prevents many farmers from having consistent access to irrigation systems (Millimouno et al., 2024).

The river flow in southwest Oromia is very strong and has a lot of potential for irrigation. Diesel pumps work well for irrigation in the region's difficult terrain, but their high fuel and capital costs keep them from being extensively adopted (Meseret et al., 2024). The spiral tube water pump, which uses an undershot water wheel attached to a spiral tube, is a good substitute. By forcing air and water into the tube, the revolving wheel creates pressure that enables the pump to run without fuel or energy. Water may be pushed horizontally up to 70 meters and raised vertically up to 30 meters with this technique. The irrigation requirements (such as the distance and water volume needed) and the water source's flow rate are the two main determinants of the spiral water pump's size and material costs (Meseret et al., 2024).

Research suggests that multi-layer coil pumps, when designed with water entry from the upper layer, offer higher discharge rates and better performance (Desta et al., 2023). These pumps can deliver more than 12 liters per minute under pressure heads of up to 12 meters. Built with local materials, these pumps are easy to maintain and suitable for rural agricultural applications (Millimouno, 2022). For long-term sustainability, careful fabrication of the rotating joint and site-specific considerations are necessary to ensure optimal performance (Teka et al., 2017).

There is currently a spiral water pump at the center that was first created by earlier scholars. The pump is presently operational and could be installed at possible locations throughout the area with additional adjustments and enhancements. This project aims to evaluate the efficacy of the pump using a participatory on-farm assessment (Millimouno et al., 2024).

1.1. General Objective

To evaluate the field performance and user perception of a spiral water pump through participatory on-farm experiments under varying head conditions.

1.2. Specific Objectives

1. To test the spiral pump's discharge, RPM, and efficiency under different pumping heads (2m to 12m).
2. To determine the optimal head range for maximum pump efficiency and water output.
3. To collect and analyze feedback from farmers regarding the pump's usability, maintenance, and operational benefits.
4. To recommend suitable applications and installation methods for the sustainable and cost-effective use of spiral water pumps in rural irrigation

2.0. Materials and methods

2.1. Material

Pump manufacturing materials

Hose, Sheet metal, Angle iron, fitting material, Bearing Instruments for data collection, 60L Container, Stopwatch, Hose, Meter, and Water level.

2.2. Methods

2.2.1. Study Area

Selected farmer farms along the Bulbul and Kersa Rivers in the Jimma Zone, which is in the Oromia Regional State in southwest Ethiopia, were the sites of the study. This area is perfect for evaluating inexpensive, river-powered irrigation technology like the spiral water pump because of its extensive river networks and rain-fed agriculture.

The Jimma Zone has a humid subtropical climate and is located between latitudes 7°15'N and 8°56'N and longitudes 35°52'E and 37°37'E. With a noticeable wet season from May to October and a dry season from November to April, the region receives 1,200 mm to 2,000 mm of rainfall on average each year. Depending on height, the average yearly temperature ranges from 12°C to 28°C.

Because of their perennial flow, appropriate velocity, and accessibility, the Bulbul and Kersa Rivers were chosen to test spiral pump performance at various heads because they offer the reliable hydrological conditions required. The surrounding terrain supports mixed smallholder farming since it is gently sloping and typical of the highland-to-midland transition zone.

These sites also made it possible to use a participatory assessment strategy, in which farmers participated directly in the process of testing and providing comments. To validate the pump's practical efficiency, usability, and sustainability in local field settings, the study sites provided authentic agricultural conditions.

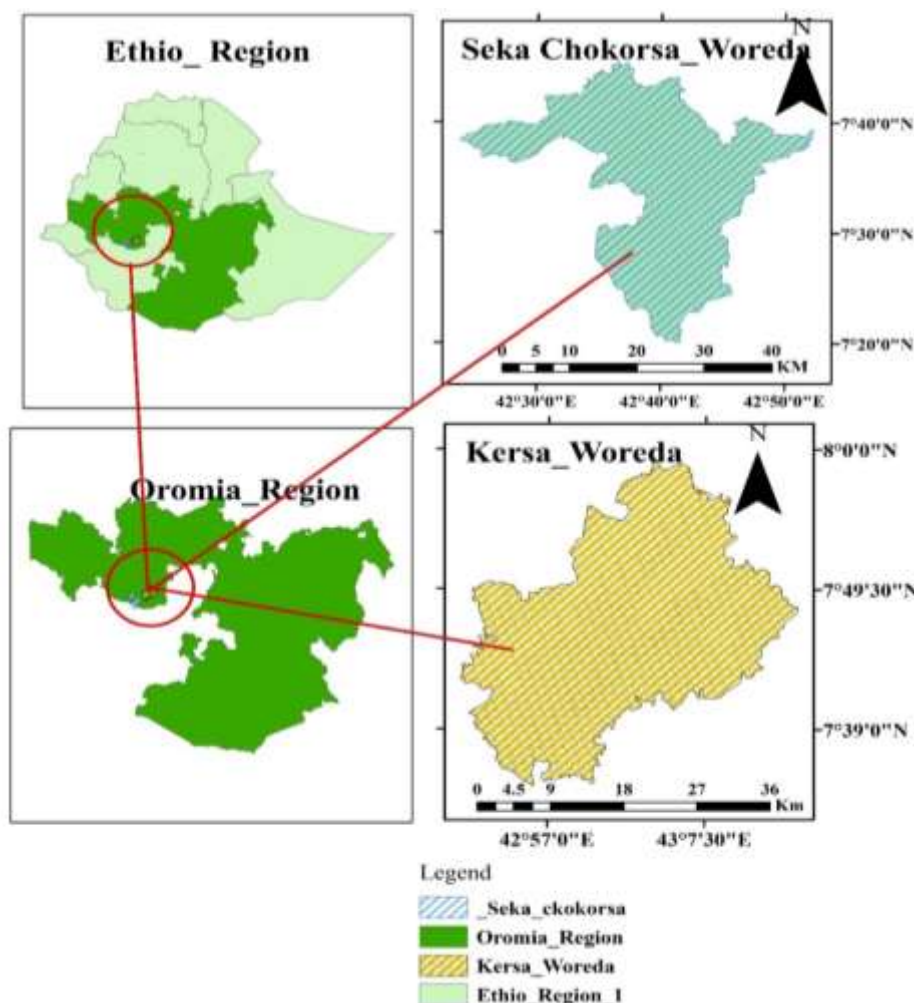


Figure 1. Study area map.

2.2.2. Treatment and data collected

The treatments considered for the experiments were six different heads (2m, 4m, 6m, 8m, 10m, 12m) with three replications.

Data collected were: Time taken to fill the known volume container, Number of rotations (RPM) of the spiral wheel, and speed of river water flow.

2.2.3. Parameters estimated

Pump discharge

The pump discharge was calculated for two levels of pipe diameter (1inch) winding the spiral tube on both the right and left sides. The pump discharge in m^3/s calculated by dividing the amount of water filled to the known volume by the measured time.

The capacity of the pump was calculated by,

$$Q = \frac{V}{T} \quad (1)$$

Where: $Q = V/T$ discharge of the pump, L/s; V = volume of water to fill the measuring drum, L; T = time required to fill the drum, s.

Efficiency of the water pump (η) is equal to the Power output (the power gained) by the fluid from a pump divided by the maximum power of the flow (Power input in a water wheel).

$$P_i = \left(\frac{1}{2}\right) \rho A v^3 \quad (2)$$

Where: P_i = power input, ρ = density of water = 1000 kg/m^3 , A = area of the blade, V = velocity of the flowing water (From our experiment data), Area of the blade $A = L \times W$, Length of the blade (L) = 0.75 m , Width of the blade (w) = 0.2 m , The radius of water wheel turbine blades (R) = 0.931 m , Calculated rotational speed of the water wheel (RPMc) = V / R .

The Power output (the power gained) by the fluid from a pump,

$$P_o = \rho Q g h \quad (3)$$

Where: ρ = density (kg/m^3), Q = volume flow rate (m^3/s), h = head (m), g = acceleration of gravity (9.81 m/s^2).

2.3. Data analysis

The data was analyzed using descriptive Statistical software.

3.0. Results and Discussion

3.1. Effect of Head on Discharge

According to the research, outflow tends to decrease as the head rises. When the head rises from 1 to 2, the discharge first decreases marginally from 0.27 to 0.25. Nevertheless, the discharge drops even more precipitously at a head value of 2. According to this inverse relationship, a lower discharge rate is the outcome of greater head values. This can be the result of the system's increased pressure or resistance, which limits the flow. According to the results, a maximum discharge of 0.25 liters per second was achieved at a head of 2 meters, while a minimum discharge of 0.06 liters per second was achieved at a head of 12 meters. The outcome is comparable to that of (Teka et al., 2017). This pattern is in line with fluid dynamics principles, which state that a gain in elevation head usually results in a decrease in volumetric flow rate due to greater gravitational and frictional forces acting against the flow (White, (2011), Fluid Mechanics, McGraw-Hill). The observed data reveal an inverse relationship between head and discharge. As discharge increases, the head decreases; this phenomenon is well-documented in pump theory and can be attributed to the increased hydraulic losses associated with higher flow rates (Cohen, et al 2009).

Although the pump can manage a range of flow rates, its capacity to produce pressure decreases as the flow rate rises, as evidenced by the head drop at larger discharges. This behavior raises the possibility that the pump is best suited for applications requiring lower discharge levels. Such performance characteristics are anticipated in centrifugal pumps, where friction losses and other hydraulic considerations cause head to be inversely proportional to discharge (Boulton, 2004).

According to the concepts outlined by Cohen et al. (2009), head and discharge have an inverse connection. Higher flow rates cause more frictional losses, which lowers the head. Boulton (2004), who provides a detailed description of the hydraulic losses in centrifugal pumps, further supports this idea.

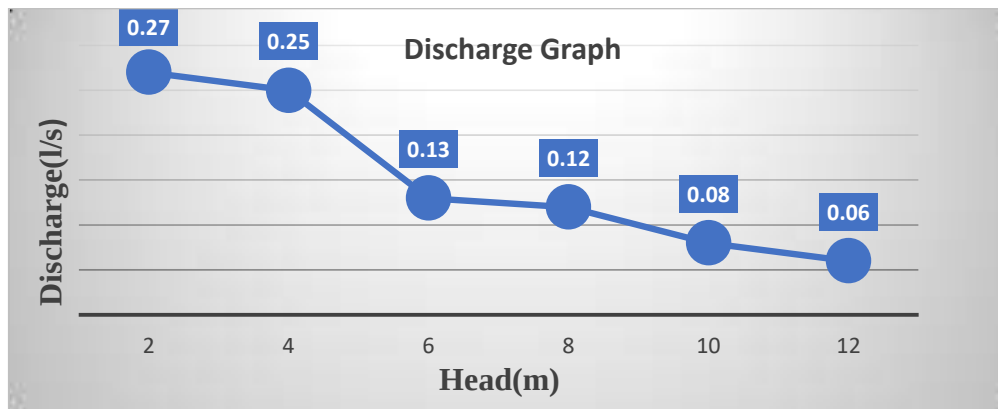


Figure 2. Head versus Discharge graph.

3.2. Effect of Head on Revolution Per Minute of spiral wheel

According to the research, RPM tends to decrease as the head increases. At a head of 1, the RPM decreases from 8.0 to 2.0. According to this inverse relationship, lower rotational speeds are the outcome of greater head values. This is probably because raising the fluid's head requires more energy, which lowers the energy available to sustain higher RPMs. According to the results, the head of 2 meters had the highest RPM of 8, and the head of 12 meters had the lowest RPM of 4.8. The outcome was comparable to (Karassik, 2001). According to Teka et al. (2019), the head (H) is directly proportional to the flow rate (Q), and the RPM is proportional to the square of the RPM

According to the data, the head rises in tandem with the RPM. This is in line with the idea that the square of the pump speed determines the pump head (Anderson, 2007). Greater centrifugal force and, thus, higher head are caused by higher RPMs.

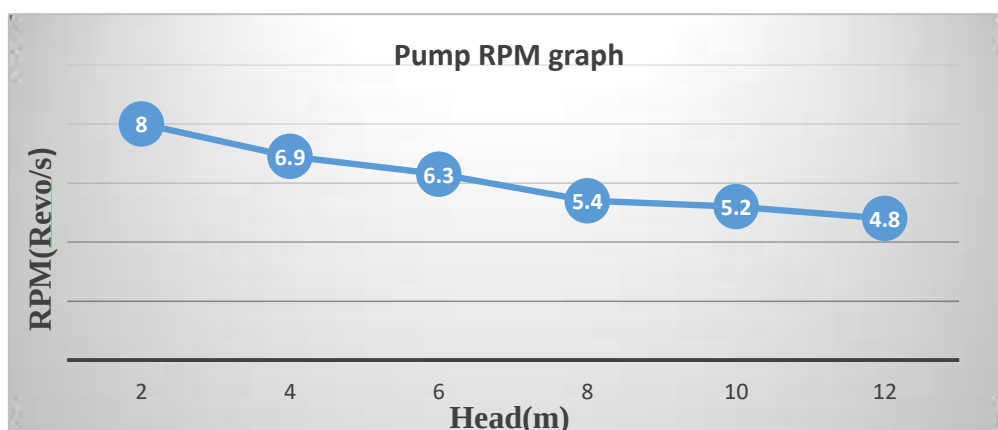


Figure 3. Head versus RPM graph.

In general, increasing RPM improves head, but it also causes the pump's components to experience more mechanical stress and power consumption. Anderson (2007) highlights the importance of managing the trade-offs between improved head and the greater energy and maintenance costs, even while higher RPM enhances pump performance.

Anderson (2007) supports the relationship between RPM and head by stating that head is directly proportional to the square of pump speed. (Cohen et al., 2009), which describes how head and overall performance are impacted by changing pump speed.

3.3. Effect of Head on Efficiency

Efficiency declines with increasing head, according to the data. Efficiency first declines from 29 to 26 when the head rises from 1 to 2, and this decline becomes more pronounced at higher head values. Higher head values probably result in more resistance and possible turbulence, which raises the system's energy consumption and reduces efficiency. According to the results, the highest efficiency of 29 was at a head of 2 meters, and the lowest efficiency of 15 was at a head of 12 meters. Similar to the findings of Teka et al. (2017), the results further support the idea that efficiency frequently declines as head increases because of increased energy losses from heat, friction, and turbulence (Streeter et al.2010. According to performance testing, depending on design factors like coil layers and submerged ratios, the spiral coil pump can attain efficiencies between 20% and 70% (Patil et al., 2014).

According to the research, efficiency tends to decline as the head increases. This implies that the pump's efficiency may decrease at higher working pressures and that its design may be adjusted for lower heads. According to Daugherty (2004), pumps are frequently made to function best within a particular operating range; deviations from this might lead to decreased efficiency.

The declining efficiency at higher heads is consistent with research in (Daugherty, 2004), which addresses how efficiency usually declines outside of the pump's ideal operating range (Hearn (2010)).

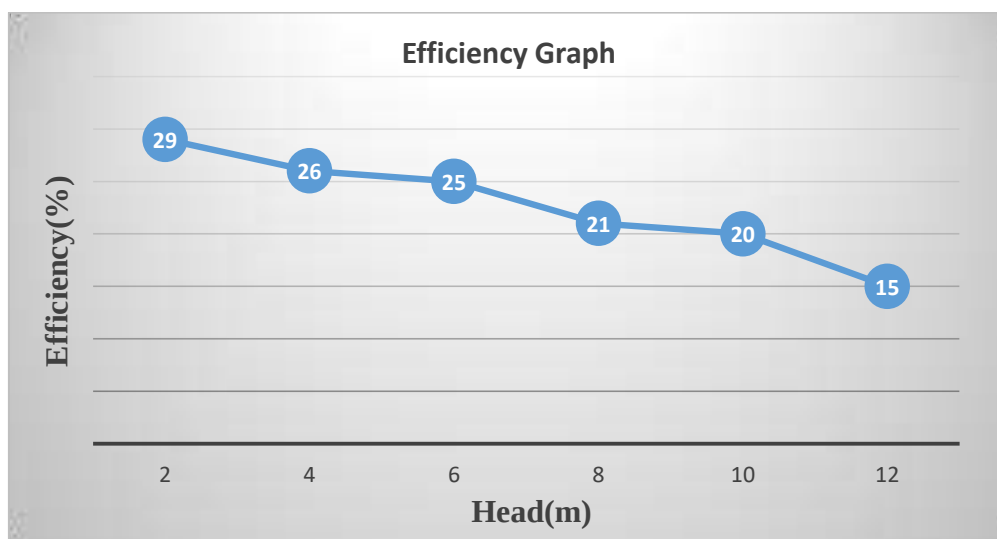


Figure 4. Head versus efficiency graph.

3.4. Farmer Perceptions

Thirteen farmers evaluate the spiral water pump technology, and their opinions can be divided into three primary groups: "Ease of Use and Maintenance," "Environmental Benefits," and "No Fuel and Minimal Operational Costs." According to the chart, five farmers value the pump because it does not require fuel and has minimal operating costs; two emphasize its benefits for the environment; and four value its ease of use and maintenance. The opinions of the other two farmers are classified as "Not Specified."

Table 1. Farmer Perceptions.

Perception	Number of Farmers	Percentage (%)
No Fuel and Minimal Operational Costs	5	38.5
Environmental Benefits	2	15.4
Ease of Use and Maintenance	4	30.8
Not Specified	2	15.4
Total	13	100.0

3.4.1. No Fuel and Minimal Operational Costs

Five farmers (38.5%) make up the largest group, and they view "No Fuel and Minimal Operational Costs" as the main advantage. Clean energy is captured by the technique, which uses the water flow itself to rotate the pump rather than fuel. This reduces expenses and reliance on outside energy sources by doing away with the requirement for fuel.

Additionally, the technology incurs no labor or operator costs, as it requires minimal intervention once installed. The absence of fuel and labor costs significantly enhances its cost-effectiveness.

3.4.2. Ease of Use and Maintenance

Four farmers (30.8%) have the second most common perception, which is "Ease of Use and Maintenance." The technology has few maintenance requirements and is made to be easy to use. Farmers appreciate how easy it is to use and how few repairs are necessary, which saves them time and effort.

Because of the spiral water pump's practical benefits, farmers have reported having good experiences with it. The pump has been favorably welcomed for its silent operation, low labor requirements, and fuel-free running. This is in line with the more general objectives of sustainable agriculture, which emphasize the need to lower operating expenses and environmental effects (Bera et al., 2023).

3.4.3. Environmental Benefits

Of the farms, just two (15.4%) cited "Environmental Benefits" as a primary benefit. Despite the fact that the fuel-free design of the pump probably promotes sustainability by lowering carbon emissions or water waste, most farmers in this category find this feature less appealing, because the farmer might not be aware of the advantages for the environment.



(a)



(b)



(c)



(d)

Figure 5. Pictures during on form data collection.

4.0. Conclusion and Recommendation

4.1. Conclusion

This study assesses the connection between a spiral water pump's head and discharge, RPM, and efficiency. According to the data, efficiency is decreased when the head rises since both discharge and RPM fall.

At a head of 2 meters, the maximum discharge was recorded, and at a head of 12 meters, the minimum discharge was 0.25 liters per second and 0.06 liters per second, respectively. The highest efficiency was recorded at a head of 2 meters, and the lowest at a head of 12 meters, which are 29 and 15, respectively.

According to accepted theories of fluid dynamics and pump operation, the pump's efficiency sharply declines at greater heads. The pump's advantages, such as its fuel-free operation and low maintenance requirements, are further highlighted by farmer feedback, which makes it a desirable choice for sustainable farming methods. Most importantly, the pump works effectively in situations where a reservoir can hold water for a full day without the need for fuel and with little harm to the environment.

4.2. Future Research Recommendations

1. Evaluate the pump over a wider range of flow velocities, wheel submergence ratios, pipe diameters, and coil configurations to optimize hydraulic performance.
2. Use a floating or vertically adjustable installation where river levels fluctuate so that the pump remains operational and protected during floods.
3. Provide adequate water-storage capacity where the measured discharge is insufficient to meet instantaneous irrigation demand.
4. Focus field applications on low-head conditions, approximately 4–6 m, while testing higher heads only where the resulting discharge and efficiency are acceptable.
5. Train farmers and operators on installation, routine maintenance, safe operation, and appropriate head conditions.

6. Advance the pump through pre-extension and demonstration activities and conduct longer-term on-farm evaluations of reliability, maintenance, cost, and farmer acceptance.

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The source manuscript does not report competing interests.

Consent for publication

All the authors contributed to the manuscript and consented to the publication of this research work.

Authors' Contributions

Abu Dedo Ilmi led study implementation, hydraulic assessment, data analysis, and manuscript preparation; Roba Adugna Maru contributed to field supervision and manuscript review; Teka Tesfay contributed technical input and review.

Informed Consent

Not Applicable

Availability of Data and Material

The underlying experimental data are available from the corresponding author upon reasonable request, subject to author and institutional approval.

Institutional Review Board Statement

Not Applicable.

Ethical Approval

Not Applicable

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Declaration of Artificial Intelligence

The authors declare that artificial intelligence tools were not used to generate, fabricate, or alter the experimental data. Any language-editing assistance used during manuscript revision did not replace the authors' responsibility for the scientific content, data, analysis, and conclusions.

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