Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT

SCHOLARLY, PEER REVIEWED

Volume 24 No. 4
April 2024

PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Afr. J. Food Agric. Nutr. Dev. 2024; 24(4): 25990-26006 https://doi.org/10.18697/ajfand.129.24215

Date	Submitted	Accepted	Published
	10th November 2023	23rd February 2024	27th April 2024

DESIGN, CONSTRUCTION, AND FIELD TESTING OF A SPIRAL WATER WHEEL PUMP

Millimouno A[1] and RA Cooke[1]

Agnes Millimouno

*Corresponding author's email: agnesm2@illinois.edu

[1] Department of Agricultural and Biological Engineering, College of Agricultural Consumers and Environmental Sciences and The Grainger College of Engineering, University of Illinois at Urbana-Champaign, United States of America

ajfand Since 2001
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

ABSTRACT

The global expansion in farmland and the increase in the world population has compounded the need for more efficient water use. The spiral water wheel pump can be a valuable and low-cost option for pumping water for surface and subsurface irrigation for farmland near flowing water bodies. This low-cost water-lifting device, which uses the kinetic energy of a flowing stream/river to lift water to homes and farmlands, can help smallholder farmers expand the growing season into the dry season. It is more cost-effective than conventional energy sources. It can be used in areas with limited access to electricity or fossil fuels because the energy of pumping is derived from the kinetic energy of flowing water. Its simplicity, adaptability, and low maintenance requirements make it a valuable tool for communities seeking water security and improved livelihoods. The main objective of this study was to develop performance curves for a version of the pump fabricated from polyvinyl chloride (PVC) and wood, materials that are readily accessible to smallholder farmers in Africa, to optimize its performance for different field conditions. Laboratory and field tests were performed in Illinois, United States of America, and Sierra Leone, West Africa, with pumps with several pipe diameters/pipe configurations and wheel diameters. During the laboratory tests, a 0.6m diameter single-layer pump with a 2.5cm pipe diameter (18 coils) lifted water to a maximum height of 3.4m. When a 3.8cm pipe diameter (10 coils) was used, the maximum height was reduced to 2.7m. Field tests at an experimental site in Fulton County, Illinois, generated a maximum height of 3.4m and 3.1m when 2.5cm pipe diameters were used on 1.22m and 0.6m diameter wheels, respectively. In Sierra Leone, the maximum height generated was 16m and 8.5m for the 1.22m and 0.6m diameter wheels, respectively, with a 1.9cm pipe diameter. In all the field tests, the pumps only worked when the water velocity exceeded 0.6 ms^{-1}, smaller streams with a velocity less than 0.6 ms^{-1} can be channeled if necessary. These results indicate that this pump can improve dry season productivity for farmland near the flowing water bodies in developing countries like Sierra Leone.

Key words: Wheel diameter, pipe diameters, pipe configuration, discharge rate, stream velocity

INTRODUCTION

Water, an essential natural resource, provides numerous vital services for human existence and development Fu *et al.* [1]. It is becoming more difficult to supply enough water due to changes in land use for agriculture, infrastructure, and mining to support an increasing world population. Irregularities in water's spatial and temporal distribution and the disparity between water availability and demand severely constrain sustainable agricultural productivity Bryan *et al.* [2].

In the past, water from remote supplies was transported by gravity. Human and animal-driven equipment was employed to lift water to fields and residences because no fossil fuel or electrically powered machinery existed [3]. These tools have now been superseded by machines that run on fossil fuels and electricity.

Climate change has driven significant changes in precipitation patterns, the frequency and magnitude of floods, surface and groundwater shortage, surface runoff, and water availability for human activities [4]. In many rural areas, limited access to adequate water supply severely limits agricultural productivity in the dry season.

In Sierra Leone, as in many African countries, agricultural productivity mainly depends on rainfall. Limited surface and subsurface water availability in the dry season adversely affects Sierra Leone's productivity. Supplemental irrigation will allow farmers to extend production into the dry season. However, irrigation requires a continual water supply. According to Lowder and Raney [5] and Morgan [6], smallholder farms' lack of such supplies aggravates crop failure and food insecurity.

Energy sources to power diesel or electrically operated machines for lifting water to homes and farmlands are becoming scarce due to the steady depletion of fossil fuels and increasing fuel prices in the global market. In addition, the depletion of fossil fuel sources and their potential adverse environmental effects have generated interest in utilizing non-polluting water-lifting devices, Yannopoulos *et al.* [7]. One such device is the spiral water wheel pump, powered by the kinetic energy of flowing water [6, 8]. This low-cost water pumping device may be an effective alternative to new pumps in most rural areas near flowing water bodies in sub-Saharan Africa, helping to alleviate food insecurity's acute and pervasive problem. The objectives of this study were to design spiral water wheel pumps from materials readily available to African smaller-holder farmers, to develop performance curves for these pumps, and to field-test them in Illinois and Sierra Leone.

ajfand Since 2001
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

The pump shown in Figure 1 below was configured so that the average person with little instruction could assemble and disassemble them as needed.

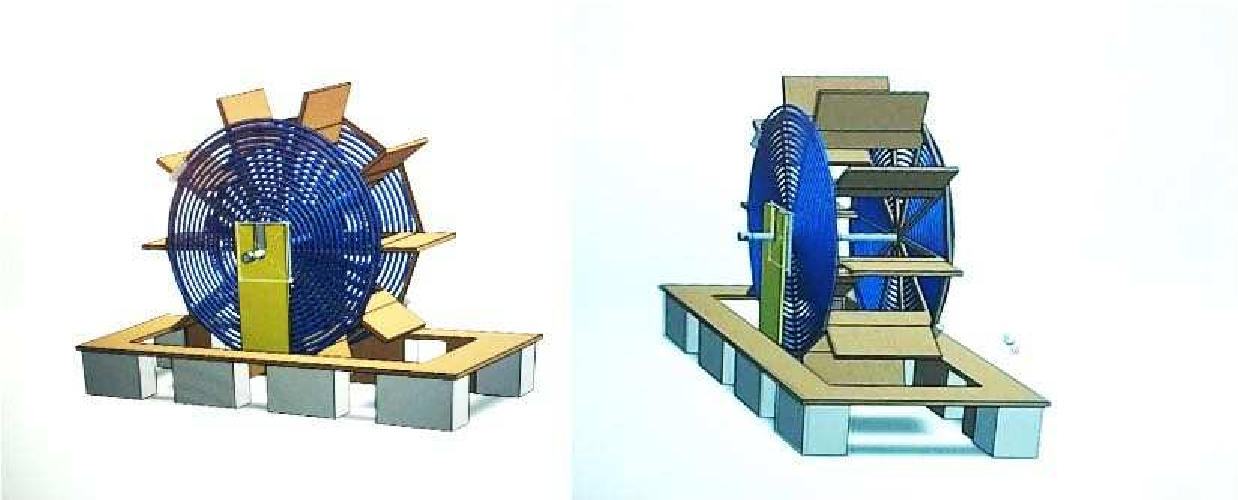

Figure 1: The design of the 1.22m wheel pump prototype for the field test in Sierra Leone

MATERIALS AND METHODS

Material Selection, Fabrication, and Description of the Wheel Pump

The wheel pumps were fabricated using readily available materials (wood and flexible plastic hose) which are easily accessible in remote areas in Sierra Leone. The material selections for fabricating the field type-test spiral water wheel pumps were purposely selected to make the pump easily accessible and affordable to smallholder farmers in Sierra Leone and other countries in sub-Saharan Africa. Hence, the pump is relatively inexpensive to construct. The pump's low maintenance requirements, primarily cleaning and checking, and the availability of local artisans for repairs are additional benefits. Figures 2a and 2b show the field-type wheel pumps tested in Illinois and Sierra Leone. The differences in the fabrication of the two spiral wheel pumps are the absence of bearings for the wheel pump fabricated and tested in Sierra Leone (Figure 2b) and the materials used for the pontoons (five-gallon drums). The wheel pump design in Illinois (Figure 2a) had bearings, and the pontoon was made with PVC pipes. The main reason for excluding the use of bearings during the fabrication of the wheel pump in Sierra Leone was to make the pump cost-effective and affordable for smallholder farmers. The cost of two 38.1mm diameter bearings used on the wheel pump in Illinois is more than the total construction cost of the wheel pump in Sierra Leone.

The spiral wheel pump consists of a flexible plastic hose with an inner diameter of 2.5cm coiled around the 1.22m wooden wheels (Figure 2). The pedals were made to be partially submerged in the creek/river, flowing at a velocity exceeding 0.6 ms,

ajfand Since 2001
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

capturing the kinetic energy of the flowing water, thereby rotating the wheel. The scoops attached to the end of the inlet pipe were made larger than the coil pipe to increase the volumes of water and air entering this pipe as the wheel rises above the creek/river. The scoops should be covered with wire mesh to prevent in-stream debris from entering the coil pipe. The coil pipe was attached to a 2.13m long axle with a pipe nipple welded 0.5m from each end. The axle passes through support holes slightly larger than its outer diameter to rotate freely with minimal friction. One end of the axle is closed so that water only flows out from one end. The discharge end is attached to a rotary fitting connected to a stationary delivery pipe that conveys water to the desired location (field or reservoir).

The rotation of the scoops in and out of the water generates alternating columns of air and water in the coil pipe. With each rotation, the air columns become more compressed. Water and air are forced into the delivery pipe under pressure and delivered at an elevation above the top of the wheel.

Figure 2: The field-type wheel testing pump (a) in Illinois (with bearings) and (b) in Sierra Leone (without bearings)

Study Areas

The study was conducted in Illinois (Champaign and Fulton Counties), and Sierra Leone along the Taia River tributary (Yele town, Makali town, Mongeri town, and Kaniya village), Figure 3. The spiral water wheel pump was first tested in the Agricultural Engineering Science Building, Hydraulics Laboratory, University of Illinois, (40^o, 04'N, 88^o, 12'W) to determine the best pipe configuration for actual field tests. Three combinations of two pipe sizes were evaluated in the laboratory: 25.4mm pipe on both sides of the wheel, 38.1mm pipe on both sides and 25.4mm pipe on one side and 38.1mm pipe on the other, resulting in 10, 18, and 14 coils, respectively, using two different motor speeds (0.67Hz and 0.80Hz). A similar test on the efficacy of a water wheel pumping system was carried out by Morgan [6], and Naegel [8] nearly 1600 times. They discovered the pump was most effective

Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

(over 50%) when it had a high head, a slow rotational speed, smaller-diameter coil pipes, and a scoop between 100 and 120% of the outer coil.

Field tests in Illinois were done at the experimental site in Fulton County (40^{o}, 27.9691'N, 90^{o}, 5.5071'W), where the pump was used to supply water to one of four 1.6-hectare fields located at an elevation of 0.6m above the creek bed. The site has been planted with corn and soybean in rotation, with a peak irrigation demand of 102,790 L/day (1 acre-inch/day). In addition to two spiral water wheel pumps, solar-powered pumps were installed in the creek to supply water to the field during summer when crop consumption exceeded the water supplied by rain. Even though the spiral water wheel pumps provided water at a lower rate than the solar-powered pumps, they supplied water continuously throughout the day and night, while the solar-powered pumps only supplied water for six to eight hours on cloud-free days. Pumps were also tested on the Upper Embarrass River in Champaign County, Illinois.

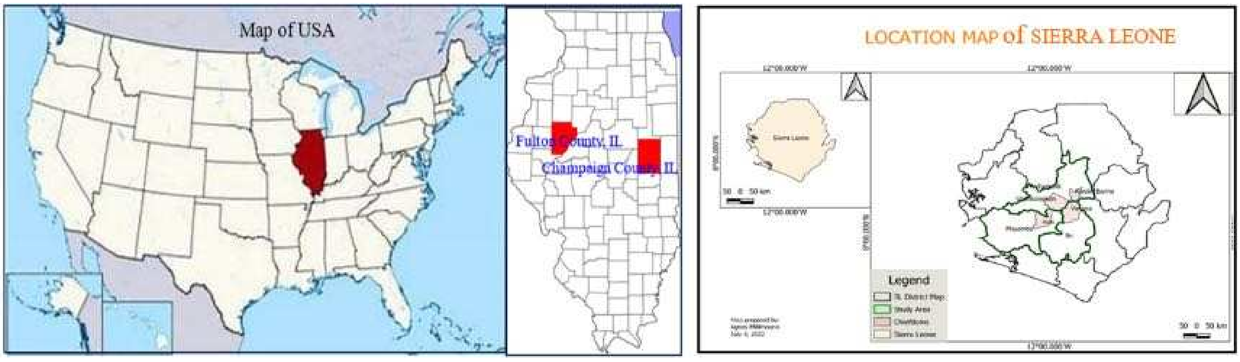

Figure 3: Map of the Study Areas in Illinois, United States of America, and Sierra Leone West Africa

Survey of Potential Sites in Sierra Leone for Deploying the Spiral Water Wheel Pump

A survey of suitable sites for deploying the spiral water wheel pump was carried out. Three districts in Sierra Leone were surveyed between January and April 2022. The Taia River, flowing through Tonkolili, Bo, and Moyamba Districts, was surveyed at different locations (Yele Town, Makali Town, Mongeri Town, and Kaniya Village). The study sites were selected based on the stream depth and velocity results.

In Sierra Leone, the survey was paired with training women and girls to use power tools, wheel pump construction, and assemble and disassemble the pump if needed. Six (6) potential University students in the Senior Secondary Level 3 in Yele town and three Undergraduate students in the Department of Agricultural Engineering, Njala University, Njala Campus, were trained. After the training and

Since 2001
ajfand
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

construction of the pumps in both locations, the wheels were installed in the Taia River in Gbonkolenke Chiefdom (Yele town) and Kori Chiefdom (Kanya village) to demonstrate the pump's performance.

The Benefit of the Low-cost Spiral Water Wheel Pump for Smallholder Farmers

In Sierra Leone, a 1.22m diameter wheel pump with a 1.9cm diameter coil pipe lifted water 16m above the water surface. The most common use of the spiral water wheel pump is irrigation during the dry season when crop consumption exceeds the water supplied by rain. This pump can improve access to on-farm water for surface and sub-surface irrigation in developing countries like Sierra Leone. The pump provided irrigation water from the Taia River along the three districts in Sierra Leone to farmlands and homes during extreme moments of the dry season (February to April). During March, the water velocity at the site in Yele town dropped below the exceeded velocity (0.61 ms^{-1}), and the pump was relocated to the site at Mongeri town, Valunia chiefdom. Figure 4 demonstrates the ability of the wheel pump to provide water to farmland close to flowing water bodies, facilitating improved productivity by smallholder farmers in Sierra Leone and other sub-Saharan countries.

The wheel was installed at Mongeri Town from March through May before the beginning of severe rains. This 0.4-hectare field is located at an elevation of 8.5m above the water surface of the Taia River. The pump lifted water 24 hours a day and seven days a week, continuously day and night, reducing women's and children's workload in fetching water from the river to irrigate the field. There was a marked increase in yield on the vegetable crops after installing the wheel pump in the stream.

In Sierra Leone, despite the year-round availability of water in streams, rivers, and creeks, there remains a big challenge in accessing on-farm water for agricultural production. This scarcity is particularly intense during the dry season, compelling women farmers from various households to unite. They collectively cultivate vegetable crops on a 0.4-hectare piece of land, by dividing the land into smaller plots.

One key to addressing this issue may lie in the use of a spiral water wheel pump. The spiral water wheel pump may reduce the burden on women transporting water to fields for irrigation and boost output during the dry season, contributing to the nation's socioeconomic development. This pump, an innovative solution, is inexpensive, low-maintenance, and is powered by the kinetic energy of flowing water. It operates effectively with a minimal water velocity and depth of 0.61ms^{-1} and 0.61m, respectively. The distance to which the pump can deliver water is determined by factors such as the change in elevation, pipe size, and pipe material (roughness). In a remarkable demonstration of efficiency in Yele town, the deployed water pump showcased its capacity to transport water across a notable distance of 150 meters. This was achieved using a pipe with a diameter of 50.8 mm, effectively channeling water from the stream directly to the farm site. The setup's effectiveness hinges on the principles of fluid dynamics, where the pipe size and elevation play pivotal roles in determining the flow and reach of water.

Interestingly, the potential for extending the water delivery distance was evident. Had the pipe been of a larger diameter, it could have facilitated a greater volume of water, thereby possibly extending the reach beyond 150m. This is because larger pipes can carry more water with less frictional loss, enhancing flow efficiency.

Similarly, the elevation difference between the water source and the water delivery destination is another critical factor. A reduced elevation gradient would have reduced the gravitational resistance encountered by the water, allowing it to flow more freely and cover a greater distance. That is if the land were flatter or the drop from the stream to the farm less steep, the water could have traveled further, potentially increasing the irrigation capacity and benefiting a larger area of the farm.

This scenario in Yele town not only highlights the practical application of basic physics in everyday farming solutions but also underscores the importance of considering environmental and technical factors in optimizing agricultural resource management.

This technology is particularly relevant in the context of the ongoing depletion of fossil fuels and the rising cost of fuel prices globally. Traditional methods of powering equipment for irrigation are becoming increasingly unsustainable. Therefore, the spiral water wheel pump, made from lightweight, durable, and locally available materials, presents a sustainable alternative. Its design considers the harsh rural conditions of Sierra Leone, as well as the physical limitations, cultural preferences, and limited literacy and technical skills of many local women farmers.

Most technologies used in developed countries for irrigation are either unknown or unaffordable for farmers in developing nations. The spiral water wheel pump, however, is designed with these rural settings in mind. It is simple enough for an average person to install and disassemble as needed, enabling farmers to extend their growing season into the dry season through irrigation.

The initial testing phase of the pump involved monitoring its performance under normal field operating conditions, and assessing its efficiency in water delivery,

Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

ease of use, and durability. Crucial to this process was the active participation and input of women farmers. Their firsthand experience with local farming conditions and challenges ensured that the adaptation of the water wheel pump was both relevant and effective. Regular feedback provided by the farmers during field testing was essential for identifying and addressing any issues. Based on this feedback, modifications were made to the pump design, including adjustments in size, materials used, and installation location, considering the minimum stream depth and velocity required. Their involvement not only contributed to improving the technology but also fostered a sense of ownership and acceptance, which is vital for the long-term success and sustainability of the new technology.

Figure 4: The difference in field crop development before (a) and after (b) the installation of the pump

Data Collection Methods

The laboratory and field tests focused on characterizing the relationship between the number of coils (different pipe diameters) and pipe configurations to obtain a maximum achievable head and discharge during the laboratory trials. The field tests focused on the relationship between (i) the size of the inlet scoop, (ii) pipe diameters, (iii) wheel diameters, and (iv) stream depth and velocity. The different wheel diameters used during the tests performed are shown in Figure 5 below.

Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Figure 5: Field setup for data collection on different wheel diameters

RESULTS AND DISCUSSION

Effect of the number of coils on the head and discharge rate

An increase in the maximum height and pressure height to which the water was lifted during the laboratory tests using the three different pipe configurations is shown in Table 1. The entire water height in the pipes is shown by the maximum head, which is connected to the elevated pressure at the outlet. The higher water column increases compression in the air column, allowing a higher pressure to lift water to an elevation. The pressure in the 14 coils appeared to be a weighted average of the other two configurations.

Figure 6 shows the pump curves obtained during the laboratory tests in Illinois, expressed as discharge rate versus delivery head, at two motor speeds for the three pipe configurations used in the laboratory tests. The maximum flow rate was approximately 800 liters per hour and 200 liters per hour, respectively, with 2.5cm coil pipes (18 coils) and 3.8cm coil pipes (10 coils), with no significant difference in the discharge rate at the different speeds tested. The maximum height to which water was lifted and the pressure per unit weight of water on the delivery side of the rotary joint (delivery pressure) for the three pipe configurations in the laboratory experiment are shown in Figure 6. The pressure in the 14 coils appeared to be a weighted average of the other two configurations. For 10 and 14 coils, the maximum elevation was nearly constant. Based on the tests conducted in the laboratory using different pipe configurations, the actual field tests were conducted using a single-layer coil on the wheel. The laboratory tests are in line with the study

Since 2001
ajfand
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

conducted by Setegn *et al.* [4], who found that a smaller pipe diameter with increased pipe length increases the number of coils around the wheel, thereby increasing the head lift and discharge at the outlet.

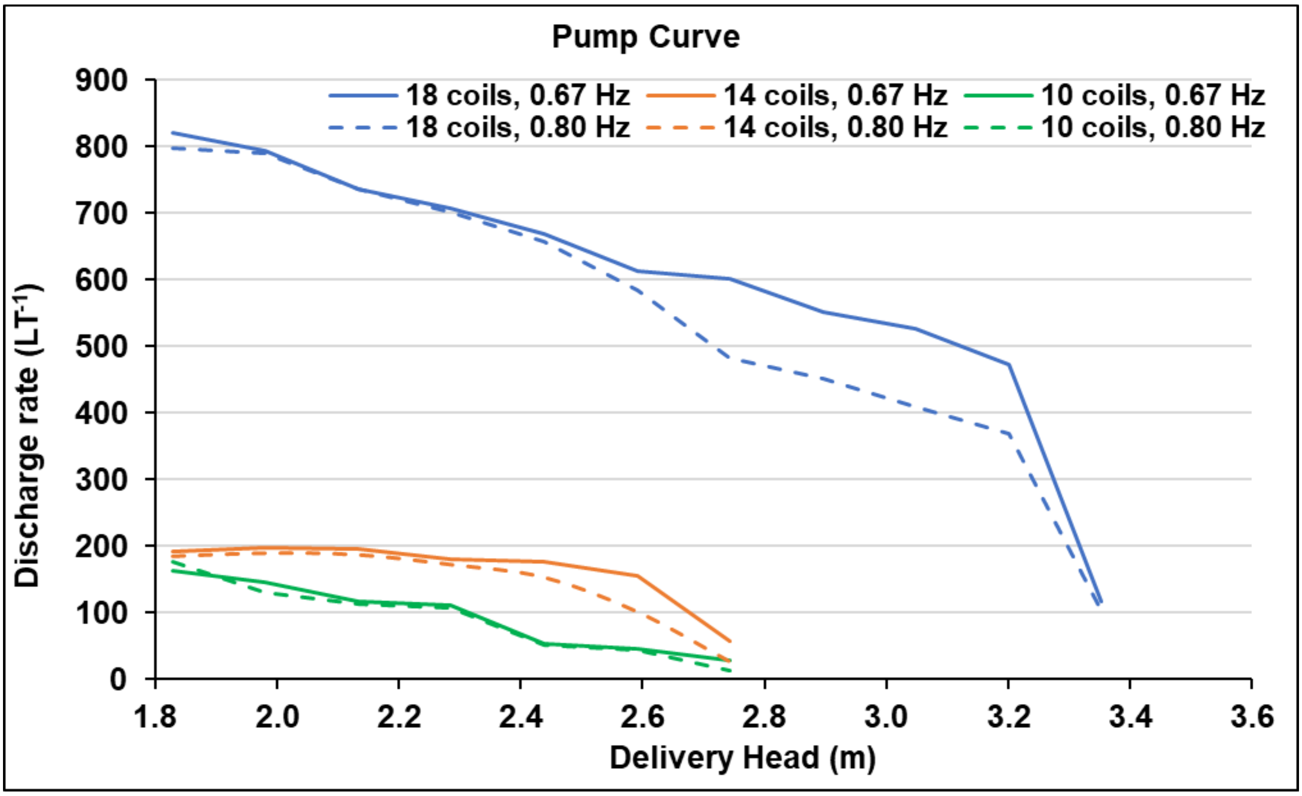

Figure 6: Pump curves obtained during laboratory tests in Illinois

Effect of wheel diameters on the head and discharge rate

The effect of wheel diameter in Illinois, tests were performed on 1.22m and 0.61m diameter wheels with 2.54cm coil pipe diameters when the stream velocities were 0.64 ms^{-1} and 0.88 ms^{-1}, respectively. In Sierra Leone, the stream velocities during the tests were 0.71 ms^{-1} and 1.03 ms^{-1} for the 1.22m and 0.61m diameter wheels, respectively, with 1.91cm coil pipe diameters, Figure 7. In both locations, the larger wheel had a greater discharge at a given discharge head and could deliver water at a higher elevation. The smaller diameter coil pipe outperformed the larger one for each wheel size due to the increased number of coils around the wheels. The smaller diameter coil pipe outperformed the larger one for each wheel size due to the increased number of coils around the wheels. However, these findings present a contrast to those reported by Kassab *et al.* [9], who observed that an increase in the number of coils does not always lead to an increased flow rate. In their research, it was noted that there is a limit beyond which additional coils do not contribute to an increase in discharge. This difference in findings could be attributed to differences in the configuration of the pump. In their study, Kassab *et al.* [9], used a single pipe-size wound around a 1.0m long 8 cm diameter horizontal drum, while in the present study, the coils were wound on top of each other, with the outer coil having a diameter of 60 cm or 120 cm. In addition, differences in the rotational speeds of the pumps between the two studies might have influenced the outcomes. Kassab *et al.* [9] conducted their experiments in a controlled laboratory setting with motor speeds ranging below and above 3.14 ms^{-1}. In contrast, the current study was field-based, utilizing water velocities between 0.64 ms^{-1} and 1.03 ms^{-1}. This variation in experimental conditions could account for the differences observed in the impact of coil numbers on water discharge.

On the other hand, they are consistent with the results reported by Naegel *et al.* [8]. They carried out different tests on a 2.0m wheel diameter using five different pipe diameters (1.91cm, 2.54cm, 3.81cm, 5.08cm, and 7.62cm) with different speeds of rotation and different total heads. They concluded that the pump was most efficient at over 50% with a high head for a slow rotational speed, smaller pipe diameter, and bigger scoop size.

The present study contrasts the result obtained by Setegn *et al.* [4]. The research conducted by Setegn *et al.* [4] studied the performance of a single-layer coil pump under varying parameters (number of coils, pump speeds, coil diameter, and submerged ratio of the pump). They concluded that multi-layer coil pumps with larger hose and drum sizes could lead to better coil pump performance.

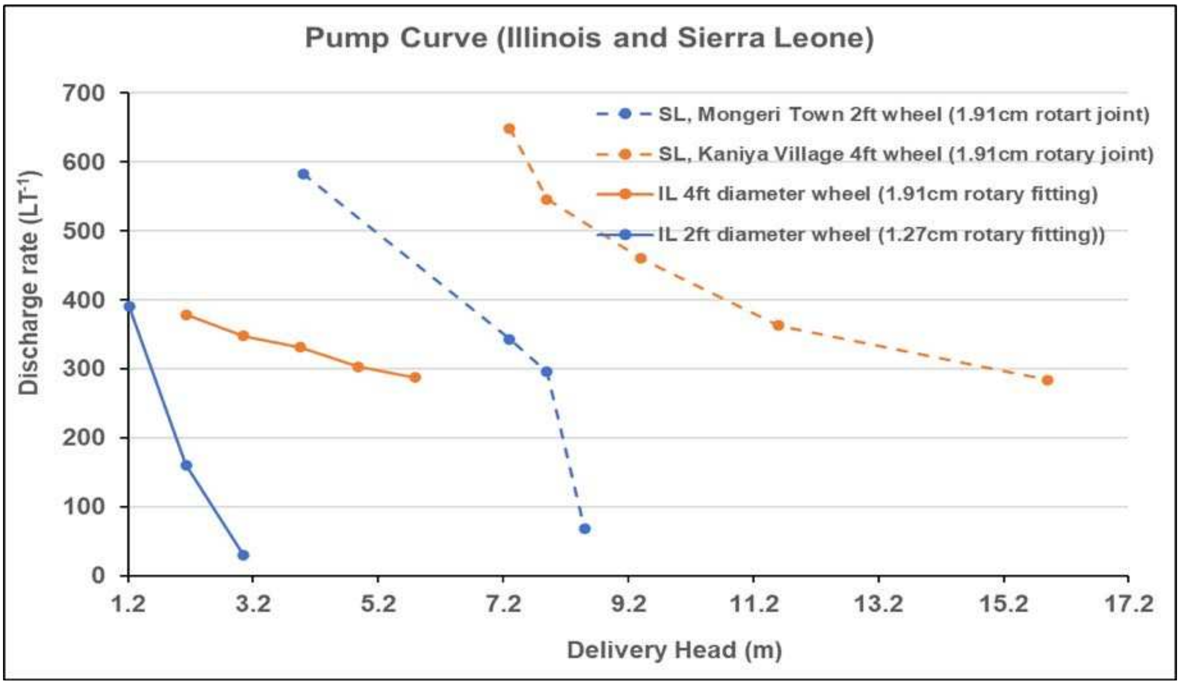

Figure 7: Performance curve obtained from Sierra Leone and Illinois during field tests for different wheel diameters (0.61m and 1.22m) with 2.5cm and 1.9cm pipe diameters

Effect of scoop size on the discharge rate

The scoop size effect was determined by changing the size of the inlet scoop on the 1.22m diameter wheel during the field test in Illinois, shown in Table 2. As shown in Figure 8, the difference in the discharge rate of the pump with a 2.54cm diameter scoop, and the discharge rates with the other two scoop sizes (5.08cm and 7.62cm), was noteworthy. However, the difference in the pump discharge rate for a given delivery head for the 5.08cm and the 7.62m scoops, was not. Hence, based on the tests conducted during the study, the 5.08cm or bigger scoop size can be suitable for a more significant discharge rate at the outlet. A bigger scoop size could help stabilize the wheel's rotational speed when experimenting with the wheel on a fast-flowing stream/river.

Effect of stream velocity and pipe configuration on the delivery head and discharge rate

Figure 8 illustrates how stream velocity and pipe configuration affect the pump's delivery head and discharge rate. Two different wheel dimeters with two different pipe sizes were used for this test: a 0.61m diameter wheel with 2.54cm and 1.91cm pipes for single-layer circular pipes and a double-layer hexagonal solid PVC and a 0.46m diameter wheel with 1.27cm pipes for a triple-layer circular pipe. The results showed an increase in the discharge rate of the pumps with a decrease in the pipe size. The triple-layer spiral has the potential for a higher delivery head and discharge rate with an increase in the wheel diameter than the double-layer and the single-layer spirals. A stream velocity between 0.61 ms^{-1} and 0.85 ms^{-1} increases the pump performance in lifting an appreciable amount of water at a high lead. An increase in the stream velocity may cause the wheel pump to rotate faster, leading to a low intake of water by the scoops, resulting in a low delivery head and discharge rate at the outlet. The difference in the discharge rate of the pumps may have occurred due to the differences in the number of coils wound around the wheel, pipe diameters used, the size of the fittings used, and stream velocity at the time of testing.

During the test, three rotary joints (1.27cm, 1.91cm, and 2.54cm) were used on different wheel diameters at the two locations (Illinois and Sierra Leone). The result in Figure 8 indicates that the stream velocity, number of coil pipes, and size of the rotary joint are the most significant aspects to consider when designing and constructing a spiral water wheel pump for better performance in different scenarios.

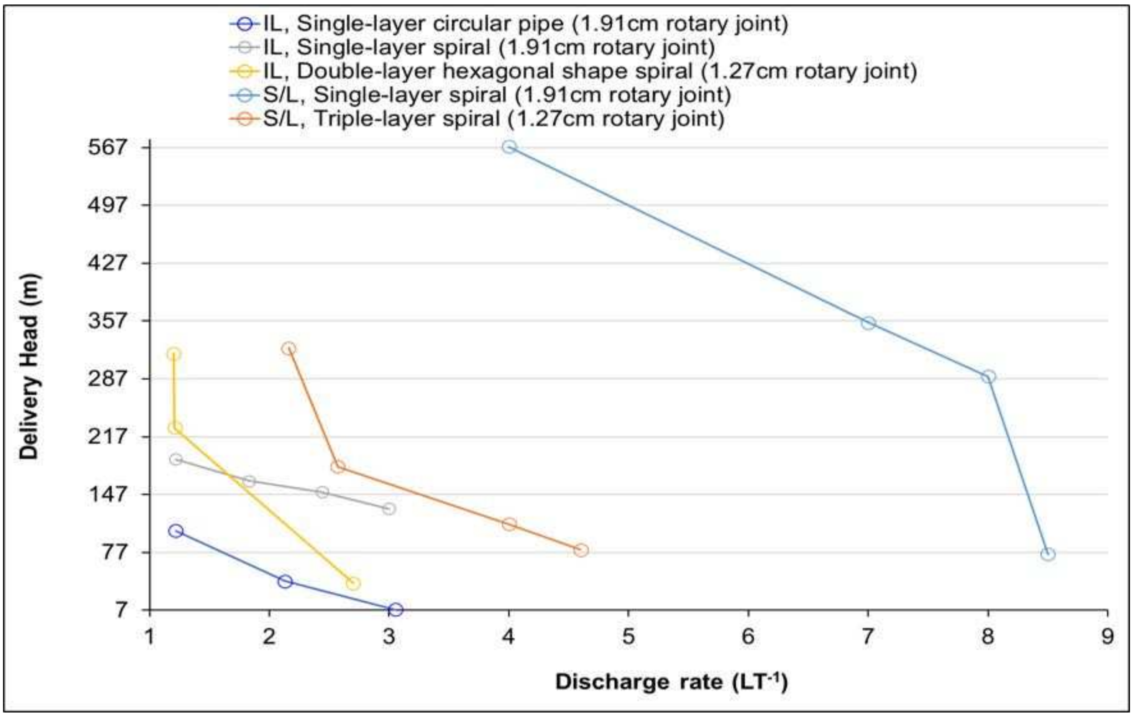

Figure 8: Effect of Stream Velocity and pipe configuration on the delivery head and discharge rate

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

According to the study, the 0.61m diameter wheel showed potential in lifting water at a higher elevation for an increasing number of coils (reduction in the pipe diameter) with a more substantial discharge. There are some benefits to having a smaller wheel diameter and less piping; it was easier to handle and less expensive to build.

The stream velocity and size of the rotary joint could lead to a better pump performance in lifting water at a higher head with a higher discharge rate at a desired location.

The spiral wheel pump's performance aim appeared to be improved by the 7.6 cm scoop or larger scoop size, which decreased the likelihood of empty wheel spins and transferred more water and air into the coil pipes to increase pressure at the discharge.

The spiral water wheel pump may reduce the burden on women transporting water to fields for irrigation and boost output during the dry season, contributing to the nation's socioeconomic development.

The following recommendations are made for future research.
The wheel pumps were prone to mechanical problems during field tests. Therefore, the coil pipe fittings should be incorporated into the connecting pipe or axle to

reduce the wheel pump's breakdown and inefficiency. The wheel pump was also prone to backflow problems. The backflow problem occurred because the coil and discharge pipes were the exact sizes. Thus, the discharge pipe should be larger than the coil pipe to reduce the friction loss in the discharge pipes, causing the backflow problem. The instrument should be guided by placing posts 0.61m to 0.91m away from the wheel to prevent in-stream debris. The spiral water wheel pump has been tested at different field levels. The spiral water wheel pump is recommended for use by smallholder farmers in Sierra Leone and elsewhere only during the dry season when the stream velocity exceeds 0.61 ms^{-1} and be removed from the stream during the rainy season if the wheel is constructed with wood, as its use is limited by seasons.

ACKNOWLEDGEMENTS

The authors are grateful to the Global Food Security Programs in the College of Agricultural Consumer and Environmental Sciences at the University of Illinois, Urbana-Champaign which funded the international application of the spiral wheel pump.

This research was supported in part by the intramural research program of the U.S. Department of Agriculture, National Institute of Food and Agriculture, Hatch (accession number:7005794). The findings and conclusions in this preliminary publication have not been formally disseminated by the U. S. Department of Agriculture and should not be construed to represent any agency determination or policy.

ajfand Since 2001
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 4
April 2024
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Table 1: Maximum height and pressure lift of the pump for different configurations

Pipe diameter (cm)	Number of coil pipes	Maximum Height (m)	Pressure (m)
3.81	10	2.7	8.5
3.81 and 25.4	14	2.7	9.2
25.4	18	3.4	9.6

Table 2: The discharge rate of the pump for three scoop sizes on the 1.22m wheel in Illinois

	Discharge rate obtained for three different scoop diameters (LT^{-1})		
Delivery Head (m)	2.54cm scoop	5.08cm scoop	7.62cm scoop
2.1	237	436	456
3.0	199	374	417
4.0	183	346	398
4.9	164	305	363
5.8	145	272	346

REFERENCES

1. **Fu B, Wang S, Su C and M Forsius** Linking ecosystem processes and ecosystem services. *Current Opinion Environ. Sustain.* 2013; **5**: 4-10.

2. **Bryan BA, Ye Y, Zhang JE and JD Connor** The land-use change affects ecosystem services value: Incorporating the scarcity effects of supply and demand dynamics*. Ecosys. Serv.* 2018; **32**: 144-157.

3. **Mays LW** A brief history of water technology during antiquity before the Romans. In Ancient Water Technologies; Springer Science and Business Media: Dordrecht, The Netherlands 2010; **1**: 1-28.

4. **Setegn SG, Rayner D, Melesse AM, Dargahi B and R Srinivasan** Impact of climate change on the hydro-climatology of Lake Tana Basin, Ethiopia. *Water Resour.* 2011; **47**: W04511.

5. **Lowder SK, Skoet J and T Raney** The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Dev.* 2016; **87**: 16-29.

6. **Morgan P** A Spiral Tube Water Wheel Pump, Blair Research Bulletin 1984; No.10 Harare, Zimbabwe.

7. **Yannopoulos SI, Lyberatos G, Theodossiou N, Li W, Valipour M, Tamburrino A and AN Angelakis** Evolution of water lifting devices (Pumps) over the centuries worldwide. *Water* (Switzerland), 2015; **7**(**9**): 5031-5060 *https://doi.org/10.3390/w7095031*

8. **Naegel LCA, Real JG and AM Mazaredo** Designing a spiral pump for irrigation. *Water lines volume.* 1991; **10**: 30-31.

9. **Kassab SZ, Ahmed A, Abdel N, Sayed E and B Abdel** Coil Pump Performance under Variable Operating Conditions. *Ninth International Water Technology Conference, Paper* 2005; **665**: 672.