International Journal on Food, Agriculture, and Natural Resources
Volume 05, Issue 04, Page 49-52
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Introduction of a siphon pump for large-scale irrigation in East Belesa district, Ethiopia

Atikilt Abera Alemayehu[1], Melkie Desalegn[1], Melaku Hunie[1]*
1) Gondar Agricultural Research Center, Gondar, Ethiopia P.O. Box – 1337, Gondar, Ethiopia
**) Correspondent author email: atikilt.3@gmail.com*

Received: 12 May 2024; Revised: 26 September 2024; Accepted: 06 December 2024
DOI: *https://doi.org/10.46676/ij-fanres.v5i4.343*

***Abstract*— Ethiopia's food supply and economy in general are largely dependent on rain-fed agriculture, which is persistently affected by drought. To counteract the recurrent drought, different water harvesting and irrigation schemes were constructed. Similarly, Dengora Earth dam was constructed in East Belesa district in central Gondar, Ethiopia. However, the dam was not functional for a long time due to the silting of the bottom sediment and water outlets. Therefore, the study aimed to transfer water over the dam crest using a low-cost siphon pump for large-scale irrigation. As a result, three siphon pumps with a diameter of three inches were installed. The discharge capacity of one siphon pump in a given reservoir is about 20.80 l/s. In reverse, the motor pump works for about 10 hours with an average fuel consumption of 35 litres per day. The technology was evaluated based on costs, efficiencies, and technical requirements through the wide participation of stakeholders. The siphon pump was selected and well accepted by the beneficiaries, and their feedback was gathered as the technology could be scaled to irrigate more areas without fuel and related costs. Therefore, a siphon pump is feasible for Dengora Earth Dam and similar reservoirs.**

***Keywords*— fuel; irrigation; reservoir; siphon pump; water**

I. Introduction

Ethiopia's food supply and economy, in general, are largely dependent on rainfed agriculture [1]. Consequently, drought has persistently affected the country and caused considerable damage to rainfed agriculture [2]. To mitigate recurrent drought, different water harvesting and irrigation schemes were constructed in the last two decades [3]. Similarly, East Belesa district is a drought-prone area and is classified among food-insecure districts [4]. The district is characterised by erratic rainfall, limited access to surface water, poor irrigation infrastructure, and a struggle to meet the food demands of its growing population.

Water scarcity is a common constraint to agricultural development in arid areas [5]. As a result, different water harvesting systems and reservoirs were constructed at the household and community levels to produce crops under irrigation [6]. However, the actual irrigated area is below the expected potential due to poor design, construction, and irrigation water management. Moreover, a source of energy to pump water is a major problem in many developing countries, especially in Ethiopia [7]. To address these challenges, the introduction of low-cost irrigation technologies, such as siphon pumps, is essential to increase agricultural production and improve the livelihoods of farmers in Dengora irrigation scheme.

Dengora Earth Dam is one of the reservoirs located in East Belesa district that became functional in 1999 after three years of construction. The reservoir covers an area of 9 ha, with a total command area of 106 ha. A total of 107 male and 9 female households benefited from the irrigation scheme. However, the dam was not functional for a long time due to the silting of the bottom sediment and water outlets. To alleviate the problem, solar and fuel pumps were installed with expenses of 500,000 and 25,000,000 ETB, respectively. However, the technical requirements of the solar pump and the fuel costs of the motor pump were very high and difficult to afford for the farmers. Therefore, to alleviate and cope with the situation, the use of large-scale siphon pumps regulated with valves could be an attractive and easier transportation system for such types of irrigation schemes.

A siphon pump is a bent pipe that is used to transfer liquid from a reservoir at a higher elevation to a lower elevation without the need for mechanical pumps or electricity when the reservoir and command areas are separated by a hill [8]. The driving forces for the action of the siphon pump are atmospheric air pressure, cohesion forces, and gravitational forces to create a continuous flow of water [9]. Therefore, the siphon can deliver water only when the reservoir elevation is higher than the delivery point elevation, while the minimum change of height for water transportation is 0.05 meter [10]. If both the reservoir and delivery height are at the same level, there is no gravity to make it work.

Meanwhile, the siphon is used to pump the water with gravity from the reservoir, which does not have an outlet. Therefore, the use of fuel and solar pumps in such types of reservoirs is not feasible technically, economically, or environmentally. The siphon typically requires less material and equipment available locally compared to other pumping systems and has minimal oversight for theft when properly configured.

Therefore, the study aimed to transfer water over the dam crest using a low-cost siphon pump for large-scale irrigation at Dengora Earth dam in central Gondar, Ethiopia.

II. Materials And Methods

The study was carried out at Dengora Earth Dam, which is located in East Belesa district. Geographically, the reservoir is located at 12° 23' 59" N latitude and 38° 02' 22" E longitude. The reservoir covers an area of 9 ha, while the command area covers 106 ha of land. In total, 107 male and 9 female households have benefitted from the irrigation scheme. The reservoir is suitable for siphon pumps based on the proximity to a water source and topographic conditions that offer elevation differences, making it an ideal location. The data on dam characteristics and existing pumps in the scheme were collected. The elevation difference between the crest of the dam and the reservoir water surface was approximately 4 meters during installation. Whereas, the elevation difference from the dam crest to the pump outlet was about 20 meters. On the other hand, the horizontal distance from the reservoir water surface to the pump outlet was about 100 meters (Figure 1).

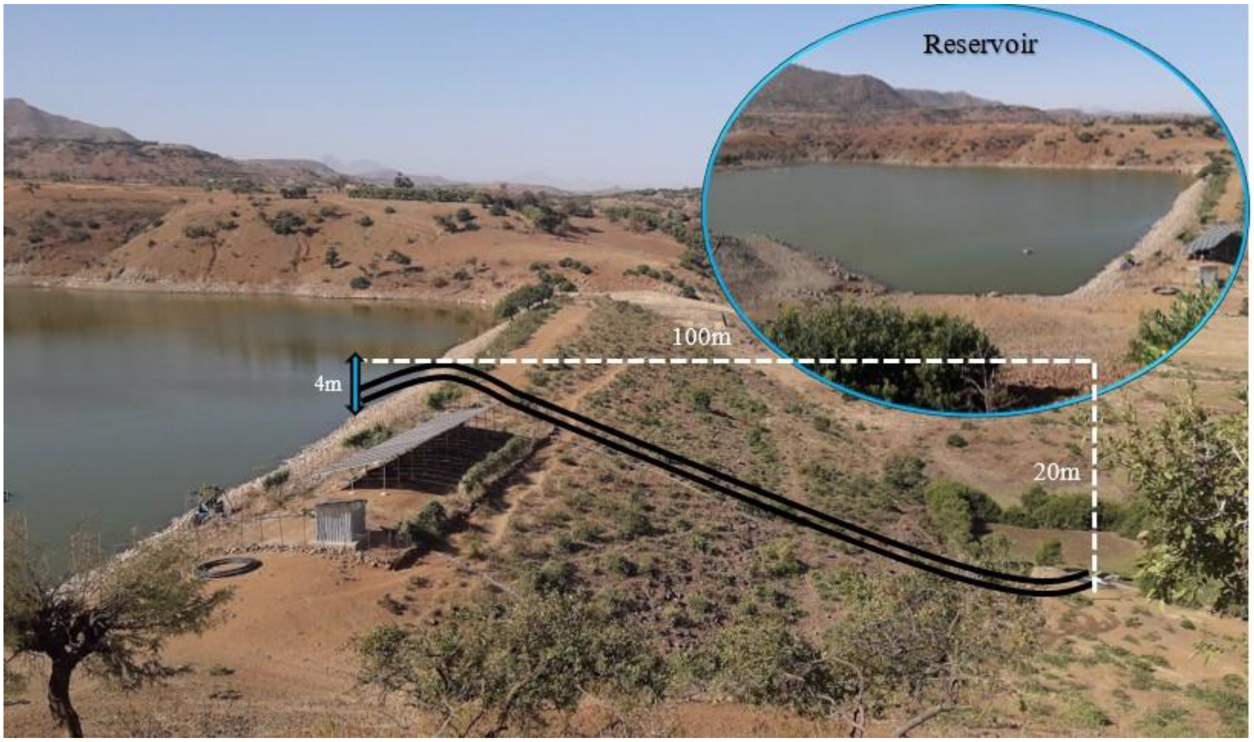

Fig. 1. The elevation difference and main components of Dengora earth dam

To determine the appropriate elevation for the siphon pump, the first measurement that should be taken is the difference between the elevation of the dam crest (DCE) and the elevation of the minimum surface water of the reservoir (RWS) [11]. Whereas, the hydraulic feasibility of the siphon pump at the site was determined according to the maximum siphon lift equation (Eq. 1). The maximum siphon lifting equation is the most important siphon design element. The equation was developed based on the atmospheric pressure at sea level

$$DCE - RWS \leq = 20' - \frac{RWS}{1000} \quad (1)$$

Where DCE stands for dam crest elevation, RWS stands for the reservoir water surface. Whereas, the flow rate for a specified siphon pipe's internal diameter and length is determined based on the equation (Eq. 2).

$$Q = \frac{\pi}{4} D^2 \left[\frac{2g\Delta h}{1.9 + \frac{fL}{D}}\right]^{0.5} \quad (2)$$

Where Q is the discharge (m3/s), D is the siphon internal diameter (cm), g is accelerated due to gravity, Δh is the operating head (m), L is the siphon length (m), and f is the friction loss coefficient (0.01) adopted from Connell [12]. Accordingly, the friction loss coefficient for plastic pipes ranges from 0.007 to 0.013, with a mean of 0.01. In this case, high-density polyethylene (HDPE) was used, which has a smooth interior surface that reduces friction and resistance to flow.

Based on the characteristics of the dam and the above-mentioned principles, the siphon pumps were installed by Gondar Agricultural Research Center (GARC). Three siphon pumps with a diameter of 3 inches were installed. The siphon pump typically requires less material and equipment available in the local market compared to other pumping methods. The materials required to install the siphon pump were HDPE pipe, a ball valve, a foot valve, a Tee, a fitting socket with an end cup, Teflon, and cement for anchorage. After all the installation process was relatively simple and required minimal technical expertise, making it accessible to smallholder farmers.

To install the siphon pump, two 50-meter-long pipes were used and the following procedures were applied: (1) Two pipes were fitted using Tee at the head of the embankment. (2) Then connect the extension pipe upward to make a priming hole. (3) Install the foot valve at the tip of the pipe to control terminal backflow to the reservoir, which should be sufficiently submerged. (4) Install the ball valve to control downstream flow and route the water to the desired location using gravity. (5) Fill the pipe with water using a refill hole as an initial priming. (6) Close the hole carefully with an end cup to avoid air in the pipe. (7) Finally, open the ball valve to start pumping. The ball valve allowed for manual startup and shutdown when we finished watering. In this case, the water could be maintained in the pipe to avoid further priming to restart the pump for later use. Because the foot valve provides an automatically closable system to prevent the reverse flowing of water, upon pump shutdown. The pump components and installation procedures are illustrated in (Figure 2).

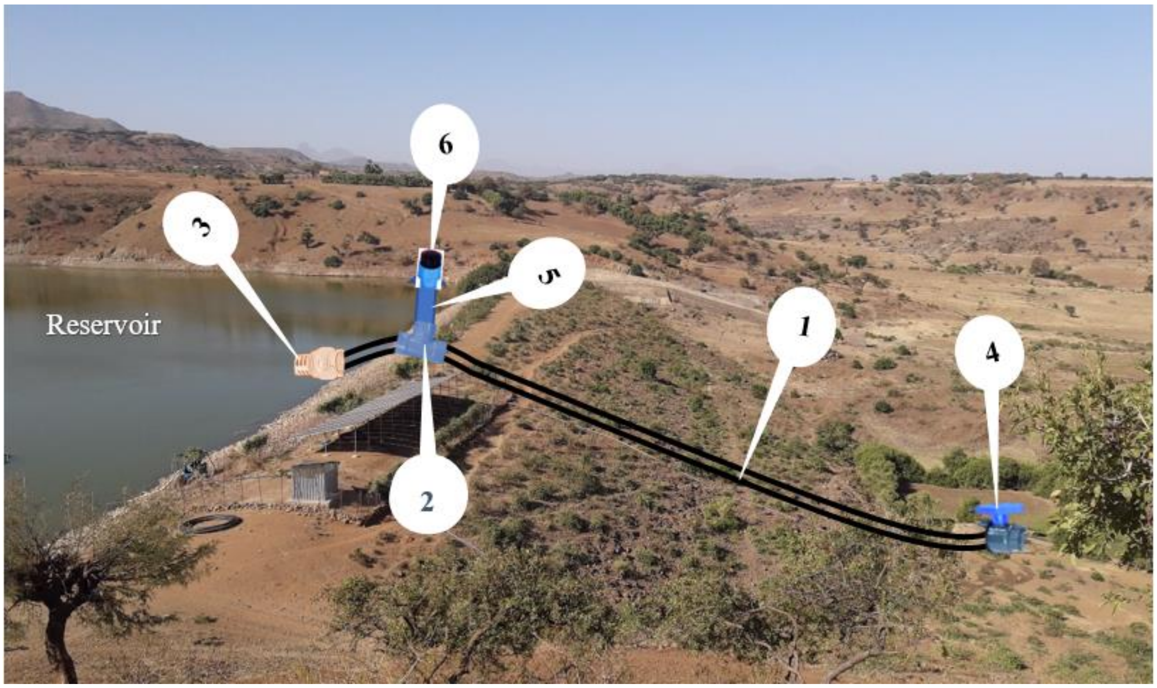

Fig. 2. Basic pump components: (1) Pipeline; (2) Tee; (3) Foot valve; (4) Ball valve; (5) Extension pipe; (6) End cup for priming

The system was fully functional when all necessary components were properly installed. The switch valve helps to keep the water in the pipe on both sides if there is a foot valve in the reservoir. Unless of a foot valve, the vacuum will be created after withdrawn of the water to the source. When the pump is switched off, there is no net pressure difference driving the water from the lower side to the higher side, and the water starts to flow back into the reservoir. The problem can be solved by using a foot valve to prevent backflow. On the other hand, the siphon has to be airtight because too much air in the system can break the vacuum that the siphon relies on to operate.

III. Results And Discussion

Based on the collected flow data, the discharge capacity of one siphon pump in a given reservoir was about 20.80 l/s (Table I). As a result, the total flow rate of three siphon pumps was 62.40 l/s, which can irrigate 50 to 60 ha of land with proper water management. When we compare the siphon pump with other pumping methods, it is relatively low-cost to install and maintain [13]. Because they do not require fuel or electricity and minimum operational costs for farmers. Most importantly, it works for about 24 hours of free energy, which makes them cost-effective and environmentally friendly options. The availability and cost of pumping power are a great concern for developing countries, especially Ethiopia, while the fuel and energy markets are becoming a challenge [7, 14]. Therefore, a siphon pump is an ideal alternative to pump the water from a reservoir that does not have a bottom outlet.

Inversely, the motor pump was working 10 hours per day with an average fuel consumption of 35 liters. The estimated costs of fuel and oil per irrigation season ranged from 250,000 to 300,000 ETB (Table II). This cost would increase farm production expenses, reduce farm profit, and decrease farmers' ability to compete in the market [10, 15]. If this trend continues for several years, the community will lose millions. In addition, the siphon pump installed using HDPE available on the local market could last up to 50 - 100 years with proper maintenance [16-18].

The characteristics of the pipe can determine the flow rate of the pump, which is proportional to the elevation and diameter of the pipe [10, 19]. Scholars argued that the flow rate decreased slightly when the length of the pipeline increased [20]. However, it should have a longer outlet leg and shorter inlet leg to allow the weight of the liquid in the longer leg to create suction [8]. Whereas, the larger diameter of the outlet pipe provides a higher discharge rate when the higher value of the head provides a higher discharge rate [10, 20, 21]. The height of the reservoir plays a great role that determining the flow rate as the gravity of water is highest at elevated height [19]. Generally, the discharge rate of the siphon pump is directly affected by pipe diameter, length, topographic condition and elevation differences as explained by Yenphayab [10].

The performance of the siphon pumps was monitored over several growing seasons to assess their impacts on technical requirements, overall costs and water availability to irrigate the crop. Field day and the technology evaluation were organized with the wide participation of farmers, extension workers, administrators, and researchers. The technology was evaluated based on costs, efficiencies, and technical requirements. As a result, the siphon pump was selected based on the above-mentioned criteria compared to other pumping methods. The technology was well accepted by the beneficiaries and the farmers requested additional siphon pumps to irrigate additional areas without fuel and related costs. The simplicity of the technology makes it scalable, allowing it to expand to more farms and regions. The system can be adapted to different topographies and water sources, making it a versatile solution for large-scale irrigation. Therefore, to alleviate and cope with the problems, the promotion of large-scale climate-friendly and energy-efficient siphon pumps are ideal option for such types of irrigation schemes.

IV. Conclusions

The total discharge for three siphon pumps was approximately 62.40 l/s, while the discharge rate tends to increase as the height of the reservoir water increases. However, the system does not work when the elevation of the water surface is lower than the elevation of the pipe outlet. Additionally, initial priming is required for siphon start-up to maintain air tightness. Meanwhile, installing a bent pipe helps to eliminate fittings, and thereby maintain an airtight system. Generally, for the study irrigation scheme and similar reservoirs, a siphon is feasible in terms of costs and technical requirements compared to other pumping methods. Most importantly, it works for about 24 hours of free energy, making them cost-effective and environmentally friendly options. Therefore, to alleviate and cope with the problems, the promotion of large-scale climate-friendly and energy-efficient siphon pumps are ideal option for such types of irrigation schemes.

Acknowledgments

The authors are very grateful to acknowledge Gondar Agricultural Research Center (GARC) and the wheat project for their financial and logistical support. Furthermore, the authors would like to thank the district office of agriculture and the farmers for their cooperation during the installation of the pipes. In particular, we would like to thank Dr. Cherinet Alem for his encouragement and financial support on behalf of the wheat project.

References

[1] M.A. Gebul, "Trend, status, and challenges of irrigation development in Ethiopia—A review," Sustainability, vol. 13, no. 10, 2021: 5646. https://doi.org/10.3390/su13105646.

[2] W. Bayu, F. Ziadat, B. Yitaferu, T. Oweis, A. Klik, H. Kendie, A. Getenet, "Selection and characterization of the Gumara - Maksegnit watershed research site, North Gondar zone, Ethiopia." In Mitigating land degradation and improving livelihoods: An integrated watershed approach, Earth Scan Studies in Natural Resource Management, 1st ed., London, Routledge 2015: pp. 21-41.

[3] G. Berhane, T. Gebreyohannes, K. Martens, K. Walraevens, "Overview of micro-dam reservoirs (MDR) in Tigray (northern Ethiopia): Challenges and benefits," Journal of African Earth Sciences, no. 123, 2016: pp. 210-222. https://doi.org/10.1016/j.jafrearsci.2016.07.022.

[4] Ahmed, Y., E. Tesfye, and M. Ahmed Yasin, "Farmers' willingness to pay for rehabilitation of degraded natural resources under watershed development: The case of Belesa districts, Amhara region of Ethiopia," Cogent Economics & Finance, vol. 10, no. 1, 2022: 2041261. https://doi.org/10.1080/23322039.2022.2041261.

[5] G. Beza, A. Wale, "Determination of Irrigation water requirement and Scheduling of onion at Low land area of Wag-himra, Northern Ethiopia," International Journal on Food, Agriculture and Natural Resources, vol. 4, no. 4, 2023: pp. 96-102. https://doi.org/10.46676/ij-fanres.v4i4.250.

[6] S. Wahyuningsih, E. Novita, I. Andriyani, I. Indarto, "The Analysis of Water Quality Compliance of Jompo River Irrigation in Jember Regency," International Journal on Food, Agriculture and Natural Resources, vol. 2, no. 1, 2021: pp. 31-34. https://doi.org/10.46676/ij-fanres.v2i1.24.

[7] A. B. Shimelis, "Performance evaluation and test of siphon pump for small scale irrigation," [MSc thesis], Bahir Dar University Institute of Technology, 2022. http://ir.bdu.edu.et/handle/123456789/14818.

[8] Kumar, A. "Siphon: Definition, Working Principle, Uses or Application," learnmechanical.com/siphon. 2018.

[9] F. Vera, R. Rivera, D. Romero-Maltrana, J.Villanueva, "Negative pressures and the first water siphon taller than 10.33 meters," PloS one, vol. 11, no. 4, 2016: e0153055. https://doi.org/10.1371/journal.pone.0153055.

[10] C. Yenphayab, "Study the engineering aspect of an advance siphon pump (Pha Ya Rangh Hai Nam) for a small farm irrigation," In IOP Conference Series: Earth and Environmental Science. 2019. IOP Publishing. https://doi.org/10.1088/1755-1315/301/1/012001.

[11] I. Morrison - Maierle, "Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown," in Montana Association of Dam and Canal Systems Conference, December, 2012.

[12] D. Connell, "Hazen-Williams C-Factor Assessment in a Operational Irrigation Pipeline," McGill University, Department of Agricultural and Biosystems Engineering. 2001, Yüksek Lisans Tezi. https://escholarship.mcgill.ca/concern/theses/fj2363897.

[13] A. Leon, A. Alnahit, "A remotely controlled siphon system for dynamic water storage management," In B. Crookston, B. Tullis (Eds.), Hydraulic Structures and Water System Management. 6th IAHR International Symposium on Hydraulic Structures, Portland, 27-30 June, 2016: pp. 1-11. https://doi.org/10.15142/T3690628160853.

[14] D. Ahuja, M. Tatsutani, "Sustainable energy for developing countries," SAPI EN. S. Surveys and Perspectives Integrating Environment and Society, 2009 (2.1). http://journals.openedition.org/sapiens/docannexe/image/823/img-1.jpg.

[15] D. Wichelns, L. Houston, D. Cone, "Economic analysis of sprinkler and siphon tube irrigation systems, with implications for public policies," Agricultural Water Management, vol. 32, no. 3, 1997: pp. 259-273. https://doi.org/10.1016/S0378-3774.

[16] K. Q. Nguyen, C. Mwiseneza, K. Mohamed, P. Cousin, M. Robert, B. Benmokrane, "Long-term testing methods for HDPE pipe-advantages and disadvantages: A review," Engineering Fracture Mechanics, no. 246, 2021: 107629. https://doi.org/10.1016/j.engfracmech.2021.107629.

[17] A. K. Mishra, L .P. Yadav, "Quality Assessment of High Density Polyethylene Pipe in Department of Water Supply and Sewerage," Journal of Advanced Research in Civil and Environmental Engineering, vol. 5, no. 04, 2018: pp. 18-33. doi. 10.24321/2393.8307.201803.

[18] S. Vlase, M. Marin, M. L. Scutaru, D. D. Scărlătescu, C. Csatlos, "Study on the mechanical responses of plastic pipes made of high density polyethylene (HDPE) in water supply network," Applied Sciences, vol. 10, no. 5, 2020: pp. 1658. https://doi.org/10.3390/app10051658.

[19] L. V. Girish, P. Naik, H. S. B. Prakash, M. S. Kumar, "Design and fabrication of a water lifting device without electricity and fuel," International Journal on Emerging Technologies, vol. 7, no. 2, 2016: pp. 112-116.

[20] A. Boatwright, S. Hughes, J. Barry, “The height limit of a siphon,” Scientific reports, vol. 5, no. 1, 2015: 16790. https://doi.org/10.1038/srep16790

[21] Y. L. Cai, H. Y. Sun, Y. Q. Shang, X. L. Xiong, “An investigation of flow characteristics in slope siphon drains,” Journal of Zhejiang University Science A, vol. 15, no. 1, 2014: pp. 22-30. https://doi.org/10.1631/jzus.A1300178