Performance Evaluation of Hydraulic Ram Pumping Systems for Small Scale Farmers: A Case Study of West Pokot County, Kenya

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Abstract

Hydraulic ram pump (hydram) has been in existence for more than two centuries. However, these pumps have been on the verge of extinction since the invention of motorized pumps, which are more powerful and efficient. Unfortunately, motorized pumps are expensive to acquire, operate and maintain. Their contribution to climate change and environmental degradation has steered the need for an alternative pumping technology. Therefore, as the world's technology shifts to green energy, hydram pumps need to be re-invented. In the late twentieth century, studies on hydram pumps have been revived with the aim of making them more efficient and economically competitive. Small scale farmers in West Pokot County, Kenya, have embraced the hydram technology, but due to low technical capacity; installed low performing hydram that operated under low efficiencies of below 30%, with the majority having operational failure due to inadequate designs. Hence, this study investigated the design and operation of these pumps. Thereafter, designed and assembled a hydram pump, using locally available materials, to supply water for domestic and small-scale agricultural use. The optimum efficiency achieved by the pump was 54%, with an optimum delivery flow rate of about 13 L/min.

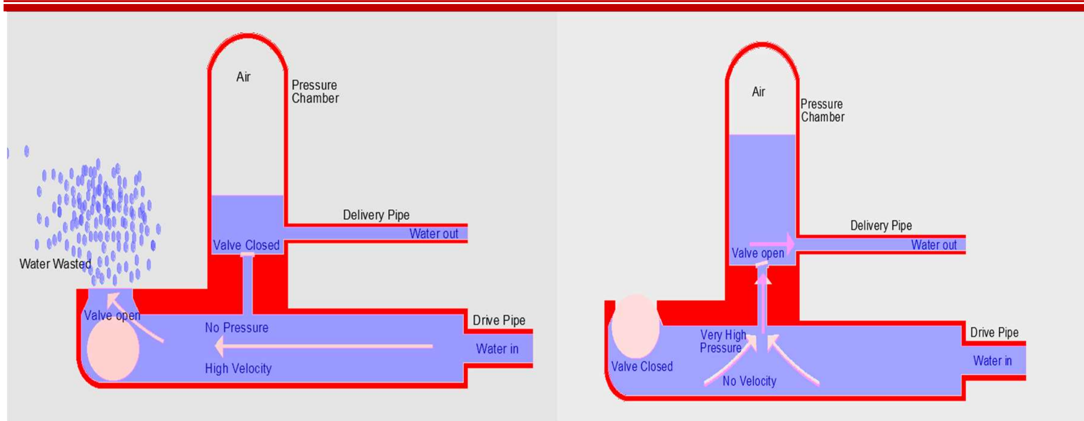
Keywords: Efficiency; Green energy; Hydram; Motorized pump; Operational failure; Optimum delivery flow rate.

1) Introduction

Water is a basic commodity essential for human, industrial, and agricultural development (Januddi et al, 2018). The need for water has been the key motivation that drives humankind to venture ways of ensuring ease access to it through various pumping mechanisms (Mishra et al., 2018). The first self-pumping machine (hydram) that did not require external energy was invented in 1796 by the Montgolfier brothers (Mohammed, 2019). These pumps were modified and utilized until the late nineteenth century after the invention of oil and electric-driven pumps (motorized pumps). Recently, the need for sustainable technology and renewable energy, especially in developing countries, has revived the interest in hydram technology (Kherde, et al., 2020).

A hydraulic ram pump is a simple pump consisting of a pressure chamber, two main valves (impulse and delivery valves), and interconnecting pipes (Sheikh, et al., 2013). The pump, with its simplicity, does not require external energy, either mechanical or electrical, to pump water (Harith et al., 2017). It utilizes the energy of water falling from a higher head, drive head, to pump a portion of the same water to a higher head, delivery head (Veljko et al., 2003). The operation of hydraulic ram pumps depends on the water hammer phenomenon that results from the sudden closure of the impulse valve (Tacke, 1988). The water hammer effect generates waves that open the delivery valve and water is delivered to a higher head (Verspuy & Tijsseling, 1993, Than, et al., 2019) see figure 1. The operation of a hydram is intermittent due to the cyclic opening and closing of the waste and delivery valves (Januddi, et al., 2018). The closure of the waste valve creates a high-pressure rise in the drive pipe. An air chamber is required to transform the high intermittent pumped flows into a continuous stream of flow (Rajaonison & Rakotondramiarana, 2019). The air valves allow air into the hydram to replace the air absorbed by the water due to the high pressure and mixing in the air chamber. (Laxmi, et al., 2015).

The effect of climatic change and global warming has adversely affected the water supply for domestic and agricultural use. The small-scaled farmers who depend on rain-fed agricultural systems have incurred loss due to unreliable rainfall patterns (Ochieng et al., 2016). These farmers are unable to irrigate their farms due to their limited financial capabilities to acquire and operate the oil or electric powered pumping systems. The solution is to look for an alternative that is cheaper and more self-efficient, the hydraulic ram pumping system (Hussin, et al., 2017). Therefore, a more reliable and cost-effective system for irrigation during unfortunate events and also to act as a water supply is required. The most appropriate system will be hydraulic ram pumps.



(a): Flow of water into the hydram (b) Flow of water after sudden closure of impulse valve

Figure 1: Operation of a hydram pump (Source: Januddi, et al., 2018)

The hydram pumping system is not a new technology in West Pokot County, Kenya. The farmers have embraced the technology because the area is endowed with a good river network system with good potential drive head for the pumping systems. The pumping systems in West Pokot are mainly used to supply water from the flowing rivers and streams for the purpose of domestic use and small-scale livestock farming. Unfortunately, the locals lack the technical know-how capacity of the hydram technology and therefore have fabricated and installed hydram pumps which were performing with low efficiencies. Therefore, this study investigated the existing hydraulic ram pumping systems in West Pokot County, Kenya, to assess these systems' design and performance characteristics. A low-cost hydram was designed and fabricated using locally available materials. The pump was tested by varying the drive and delivery head and its performance was assessed. The major limitation of the study was the behavior of the existing pumps for different drive and delivery heads where they were installed. Similarly, the designed pump was observed for a limited number of drive and delivery heads with assumption that the pump will simulate the actual site conditions.

2) Materials and Methods

2.1. Existing hydraulic ram pumping systems

The investigation was conducted on eight hydraulic ram pumping systems identified in West Pokot County, Kenya. These sites were chosen based on their availability and accessibility. Figure 2 shows the existing sites that were studied. These sites include; Karas, Kaibos, Chepkono, Kabichbich, Imonpoghet 1, Imonpoghet 2, Kamsis, and Kapsait. These systems were owned by individual members except the one found at

Chepkono area that was community owned system. These systems were used to supply water for domestic purpose and for small scale-livestock farming.

The evaluation focused on the design and performance criteria of the eight pump systems. On design criteria, the following components were assessed; materials used for the system, the size of pump and pipe components and the site conditions (stream flow rates, drive and delivery head). The performance criteria included; the efficiency of the system, failures and breakages. The existing pump were locally designed and fabricated by local artisans. The process of determining the design and performance criteria of the eight existing hydram systems were;

i. Direct interview and interrogation of the owners of the sites

ii. Observations and basic measurements

2.2. Construction and Experimentation of the hydram pump

The hydram pump was designed following Pawlick et al, (2018) and Watt, (1975) guidelines. Figure 3 shows a set-up of the hydram pump as done by Hussin, et al., (2017). The designed system was fabricated using PP-R pipes and fittings and GI fittings, as shown in Figure 4, since these materials are cheaply available and they have higher strength capacity to resist the pressures generated within the pump.

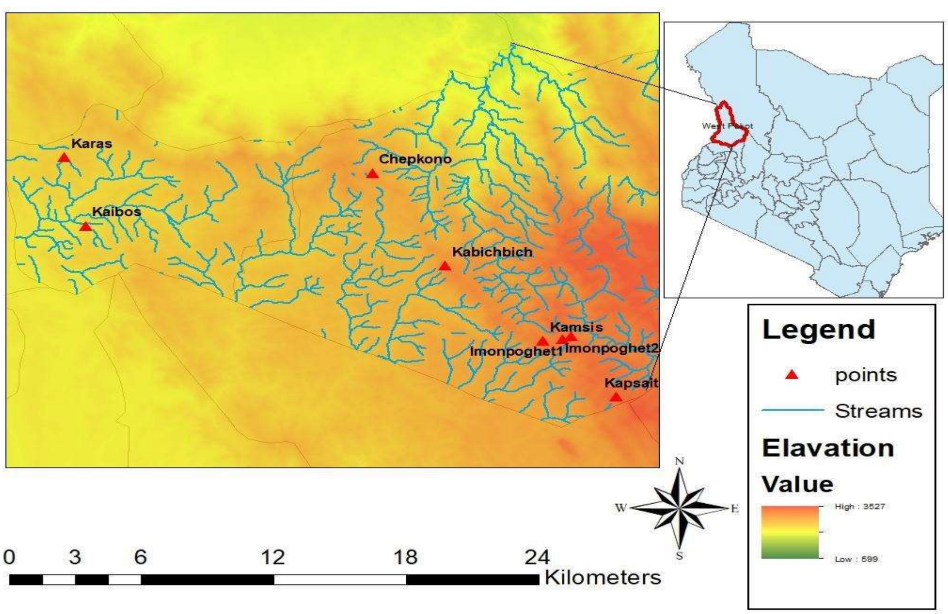
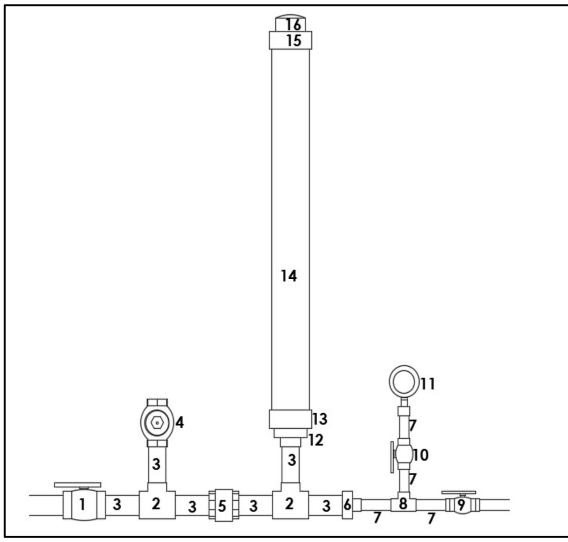


Figure 2: Location of the existing eight hydram pumping systems that were studied (Source: ArcGIS pro).



PIPE FITTINGS SCHEDULE					
ITEM	DESCRIPTION	DIA (mm)	LENGTH (mm)	CLASS	QTY (No.)
1	VALVE	32		PN 16	1
2	ALL EQUAL TEE	32		PN 16	2
3	GI NIPPLE	32	100	PN 16	6
4	BRASS SWING CHECK VALVE	32		PN 25	1
5	SPRING CHECK VALVE	32		PN 16	1
6	REDUCER	32/20		PN 16	1
7	PPR PIPE PIECE	20	70	PN 16	2
8	ALL EQUAL TEE	20		PN 16	1
9	VALVE	20		PN 16	1
10	VALVE	12		PN 16	1
11	PRESSURE GAUGE (21 BAR)	12		PN 16	1
12	REDUCER	50/32		PN 16	6
13	REDUCER	90/63		PN 16	1
14	PPR PIPE PIECE	90	1000	PN 16	1
15	REDUCER	90/63		PN 16	1
16	PPR END CAP	63		PN 16	1

Figure 3: Hydram schematic drawing for the designed hydram pump (Source: Mohammed, 2019).

(a) Components of the hydram (b) Complete assembled hydram pump

Figure 4: Fabrication of the Hydram pump (Source: Actual Site Photographs).

The drive head and the delivery head were the key parameters for investigation. The variation of both heads significantly affects the quantity of water delivered by the pump (Than, et al., 2019). Table 1 shows the drive heads and delivery heads used for the experimentation of the fabricated hydram.

Table 1: Experimental set-up parameters

Experimentation	Drive head (m)	Delivery head (m)
1	2.4	4.2
2	2.4	6.0

3	2.8	10.0

3) Results

Existing hydraulic ram pumping systems

The investigation of the existing eight hydram pumping system showed that 87.5% of hydram pumps are made up of steel. The majority of the pumps were of size 80/40mm configuration (that is, the inlet pipe size 80mm and outlet pipe size 40mm) and 80/25mm configuration (that is inlet pipe size 80mm and outlet pipe size 25mm) that constitute 50% and 37.5% respectively of the investigated pumps in West Pokot.

All sites had drive heads below 10m with delivery head above 40m and pressure chamber volume of greater than 2500 cm3, See figure 5.

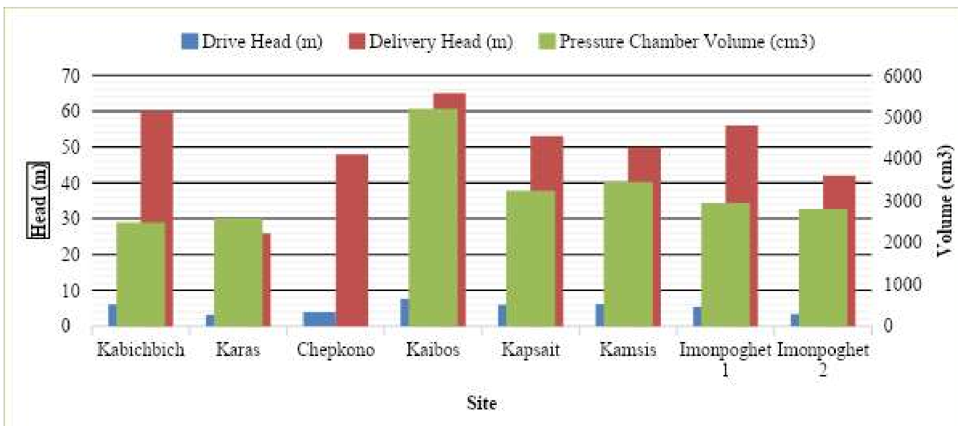


Figure 5: Relationship between drive head, delivery head and pressure chamber volume of existing eight hydram pumping systems.

These pumps had lower efficiencies of below 30% due to inadequate design of the system meaning, their designs are not tailor made to ensure pumps will be working as per site conditions (such as the drive head and the anticipated delivery heads) and pumping requirements that is the flow rates, build-up pressures and the water velocities within the pump as a results of site conditions.

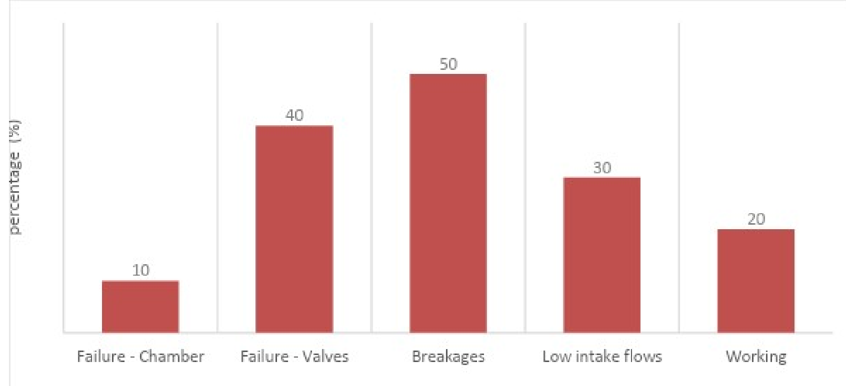


Figure 6: Performance evaluation of existing eight hydram pumps

The designed and fabricated hydram pump was able to obtain higher delivery flow rates, as shown in Figure 7. For the three experiments, a higher flow rate of 12.938 L/min was obtained on set-up 1 with a drive head of 2.4 m and a delivery head of 4.2 m. For a higher drive head of 2.8 m and delivery head of 10 m, a flow rate of 11.372 L/min was obtained.

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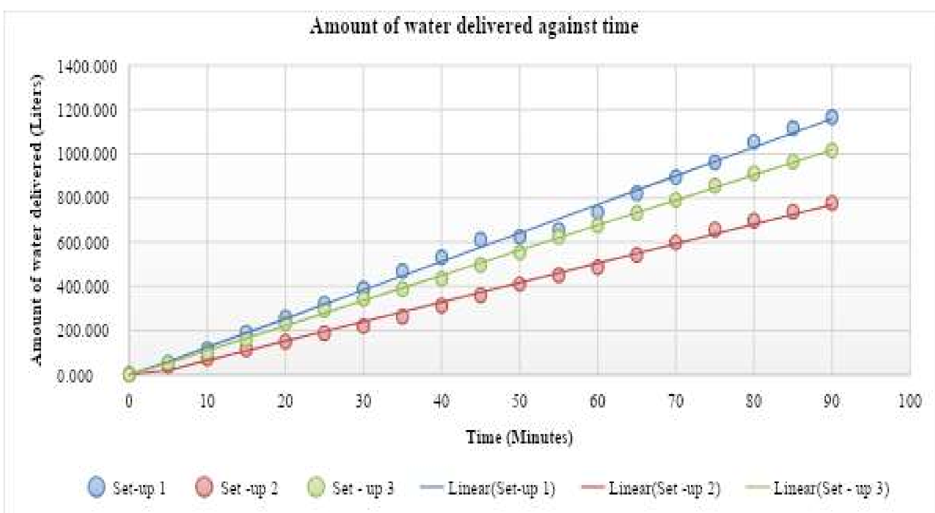

Figure 7: Amount of water delivered against time of the designed prototype hydram pump

The rate of the amount of water wasted by the pump was higher at higher heads as compared to the lower heads, see figure 8.

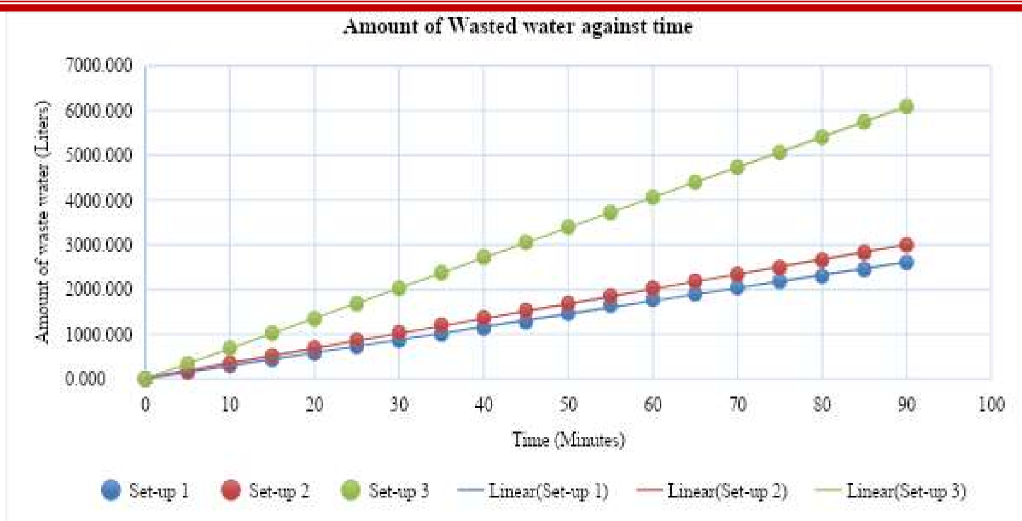

Figure 8: Amount of water wasted by the pump against time of the designed prototype hydram pump.

4) Discussion

Major cause of failure of the existing systems, was the imbalance of the pressure within the pump as a result of improper design of the valves and the pressure chamber. The efficiency of the pump depends on proper design of the valves and the pressure, since these are key controller of the pressures and the velocities of the system, which thereafter affects the pump's efficiency as observed by other workers (Kimaro, 2018).

The site conditions, drive and delivery heads and stream flows, are key components when installing the pumps. A similar observation was made by Asvapoositkul et al., (2019). The existing systems failed due to inadequate designs of the head ratio to flow ratio. The higher head ratio results to high pressure build up in the pump. This pressure is due to water hammer effect of the pump that causes a portion of water to be pumped to delivery tank (Inthachot, et al., 2015). The higher pressure generated in the pump can destroy the pump components, that is the valves, pressure chamber and pipes. Therefore, pressure chamber should be designed to absorb the pressure within the pump. This finding has been corroborated by Mishra et al, (2018).

5) Conclusions

Hydraulic ram pump has a great potential in providing alternative pumping solutions to rural population for domestic and agricultural use. The investigation carried out showed that hydram technology is well utilized in West Pokot County, Kenya. This is because it is cheaper and easy to fabricate and install as compared to motorized pumping systems.

The investigated systems, however performed with low efficiencies of below 30%. The study therefore, tries to sensitize and improve the locals' designed systems by providing a simplified designed prototype that can be used to develop new systems and also highlights on how they can improve their existing systems. From the study, the pump was able to achieve an optimum efficiency of 54% with optimum delivery flow rate of 12.938L/min, further studies can be carried out to improve the efficiency of the pump by modifying the pump, that is the valves and pressure chamber.

Acknowledgement

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