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Optimizing pumped water utilization from Modified water wheel for Drip irrigation

June C. Quipo
College of Engineering, Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, 3700, Philippines
june.quipo12@gmail.com

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Abstract

A study was conducted to improve the performance of a water-wheel pump for irrigation. The modified water wheel was tested in an irrigation canal and was capable of pumping water for 300 meters using a conveyance pipe with a head of 4 meters. Results showed that the pumping capacity achieve was 4.63m^3/hr, 3.14m^3/hr, 1.78m^3/hr, and 0.90m^3/hr at conveyance pipe lengths of 10m, 100m, 200m, and 300m respectively. Additionally, the minimum pumping capacity of the water wheel was determined to be suitable for planting 0.45ha of tomatoes, 0.22ha of eggplants, and 0.45ha of peppers. The resulting net benefit was PhP147,752 per year. The economic analysis indicates that the system is financially viable for a drip irrigation setup spanning 10m to 200m.

Keywords: Hydropower, drip irrigation, net benefit, pumped water utilization, water wheel pump.

Introduction

Water is certainly one of the major resources in farming and irrigation purposes can be drawn from surface reservoirs or from aquifers[1]. Irrigation application is among the measures that can improve yields[2]. Water pumping is the usual irrigation practice utilized by farmers especially if the water source has a lower elevation compared to its service area. Water pumping from surface water and groundwater is practice of farmers in irrigation causes high operational cost[3]. With these problems of water pumping, a renewable energy system will be used to solve to drive pump or elevate water.

Some studies use renewable energy to pump water. An optimization for a water supply of 17.1m^3/day from the wind pump and rainfall with the optimum service area would be 0.81 ha, 0.95 ha, 0.65 ha, and 0.32 ha for tomato, eggplant, onion, and rice crops[4], respectively. A direct coupled photovoltaic water pumping system can supply the domestic needs in remote areas[5]. Renewable energy resources are the best alternatives when the less amount of water[6]. A solar photovoltaic pump coupled with drip irrigation system has been for growing orchards[7]. Windmills are the most cost-effective solution with solar pumping system[8]. The net return for solar irrigated boro rice was negative due to high investment for irrigation while the yield of tomato was higher[9].

A numerous study on water wheel as potential source of renewable energy resources and irrigation. Water wheel could be used in pumping water to higher elevations[10], and reducing the greenhouse gas emissions[11]. It is obtainable in the free environment mainly on a water landscape[12] and cost effective[13,14]. The minimum current required to operate a hydrokinetic device is typically 1–2m/s[15]. The rotation of a waterwheel is influenced by several parameters including blade shape, number of blades, nozzle angle, and rim diameter[16]. Efficiency is largely dependent upon the percentage of momentum of the striking water that gets transferred to the vanes[17]. Coil pumps have potential to provide crop irrigation[18]. Spiral pumps are an excellent alternative for developing countries without their own oil resources[19]. An increasing the pumping capacity of the spiral water wheel pump, the number of coil pipes, tubular water collector, bigger diameter of water wheel, paddle submergence, and the area of paddles are recommended[20].

The adaption of an alternative technology that is cost effective, efficient and economically viable is needed to address the continuous increase cost of water pumping. Moreover, the utilization and optimization of water coming from the renewable energy pump is also a main concern. Thus, the objective of the study was to optimize the pumped water by a modified water wheel coupled with drip irrigation. Specifically, it aims to fabricate and modify the existing spiral water wheel, evaluate its performance in terms of capacity for delivering water, optimize pumped water utilization for irrigating crops, and perform economic analysis of the modified coupled to drip irrigation.

Materials and Methods

Conceptual framework used in the study: The study was conceptualized to modify the spiral paddled-type wheel pump system for irrigating high value crops. Modification was done to pump irrigation water that would provide greater discharge capacity, and higher discharge head by harnessing the energy of flowing water from an irrigation canal or river. The output of this study would be the optimization of water use from a modified water wheel for crop production. The location of the study was conducted at Nueva Vizcaya State University Bayombong, Nueva Vizcaya.

Modification of water wheel: Modification and fabrication were carried out to improve the water wheel pump system, which aimed to increase its discharge capacity, and head. The modifications were based on the recommendations and involved the spiral paddle-type water wheel pump. The design of the water wheel pump took into consideration the canal's characteristics at the selected study location and its ability to lift water at a 4-meter elevation head. Figure-2 shows the modified water wheel to pump irrigation water for drip irrigation. The components of the water wheel included a wheel, paddles, spiral coils, hollow shaft, rotary fitting, and tubular water collector or scoop. Galvanized iron sheets were used to make paddles attached to the outside diameter of the wheel. A paddle had a total surface area of 0.337m^2 with 250mm diameter and the same width as the water wheel. The wheel was made up of a 25mm x 2 mm square steel tube and supported on the center diameter. Eight PVC pipes, each with a length of 60m, were assembled in the form of a 13 spiral. This supported on the study of water wheel pump each side wheel had 13 coils of 1-inch PVC pipe[18]. Hollow shafting acted as temporary storage coming from the spiral coil. It was composed of 38.1 mm diameter solid shaft protruded to G.I pipe (50.8mm) diameter. A 25.4mm nipple was used as distribution to the hollow shaft and inclined to 45 degrees from horizontal to minimize friction of incoming water from polyvinyl pipe. Non-return (25mm diameter) valve was used just before the nipple to prevent back flow to the spiral coil during rotation of the water wheel. A tubular water collector was installed at the outside diameter of the spiral coil. The volume of water in each tubular collector was 2.38 liters, and the scoops were full of water during rotation. The frame and other braces were fabricated to support other parts and the whole device into a rigid assembly. Four PVC drums acted as a floating device for the water wheel.

Performance evaluation of water wheel: Performance evaluation of the water wheel was done to ensure it can distribute water using a conveyance pipe length of up to 300 meters and a head of 4m to a storage tank for the drip irrigation system. The equation of pumping capacity is given in the following formula.

$$Qp = vw/t \quad (1)$$

Qp: pumping pumping capacity, *vw:* volume of water coming out in water wheel pump, *t: time* to fill the volume of water using PVC drum.

Optimizing water utilization for irrigation: Prior to implementing the optimization scheme, three high-value crops - eggplant, pepper, and tomato - were selected as the usual crops planted in Nueva Vizcaya with production cost [21-22], as shown in Table-1. With the use of linear programming, it can facilitate the operation of systems, maximizing the total amount of pumped water, under a given set of constraints[23]. It can be applied in solving water resources – based problems[24]. The study determined the maximum area for each crop that could generate the most benefits supplied by a water wheel pump system. The objective function[4] used in the study with the following equation.

$$\text{Maximixe } \left(\sum Y_{pi} \; x \; X_i \; x \; P_i \; x \; N_i - \sum C_{pi} \; x X_i \; x \; N_i\right) \quad (2)$$

Ypi: potential yield of the crop, *Xi*: planted area of the crop, *Pi* :price of the crop, *Ni:* number of crop per year, *Cp:* cost of production[4]

Subjected constraints of water demand and availability of water supply. The function expressed as;

$$\sum 10 W_{di} \; x \; X_i \; x \; C_w < W_s \quad (3)$$

Wdi: water demand, *Ws*: available water supply considering pumped water coming from the water wheel, *Cw*: wetted area ratio of 0.8064 for evaluated uniformity of drip.

Economic viability of the system: The following parameters were used to determine the financial indicators to ascertain the financial viability in using the device. Net income represented the amount of money remaining after all operating expenses, interest, and taxes were deducted. Equation 4,5,6 was used to calculate the net income, payback period, and return of investment.

Net Income= Total Revenue- Total Operating Cost (4)

Payback period = Investment Cost/ Net Income (5)

Return of investment = Total operating Cost/Net Income x 100 (6)

Results and Discussion

Performance of water wheel pump to deliver irrigation water: During the performance evaluation of the water wheel pump, the canal characteristics had an average discharge and velocity of flow were 8.80m^3/sec and 0.90m/sec, respectively. An eight scoop and four scoops were selected to determine the pumping capacity. The results show that in eight scoops have a 4.63 m^3/hr capacity while four scoops have a 3.10 m^3/hr. This was supported on the study by an increase in the number of scoops leading to higher pumping capacity [20]. The eight scoops were selected in the conduct of the ability of water wheel to distribute water at 300m long with a 4m head. The distribution pipe was 300m long and consisted of 100m (50mm ϕ) duct hose and 200m (25.4mm, ϕ) polyethylene pipe. Additionally, the water wheel's performance to distribute water at a conveyance pipe with maintaining head of 4m were measured. Pumping capacity values were obtained at 10m, 100m, 200m, and 300m lengths of conveyance, with values of 4.63, 3.14, 1.78, 0.90m^3/hr, respectively.

Optimize Function Development: In optimizing the utilization of water that was supplied by the water wheel pump, the aim was to maximize the profit from a production system. In doing so, determination of the area to be planted for the different selected crops (eggplant, tomato, and pepper) normally planted in Nueva Vizcaya is necessary. Necessary input data such as production cost, yield, and market price of crops were applied in the optimization program (Table-1). The objective function was the net income determined for each selected crop. Coefficients in the constraint function were determined from the water demand of the crop in which the unit in mm/day was converted to m^3/day/yr. Wetted area ratio (Cw) were measured at 0.8064 coefficient uniformity of the drip irrigation system, corresponding to 80.64% wetted area of the three crops. The system optimization for water utilization was conducted using linear programming as the tool[4]. Optimized utilization of pumped water from the water wheel with pumping capacities of 4.63, 3.16, 1.78, and 0.90 m^3/hr were used. The objective function was solved with non-negative constraints for the service area of diversified farming (X1 > 0 ha; X2 > 0 ha; and X3 > 0, ha). For mono-crop production, the service area for the two crops was set to zero.

Optimize scheme at different pumping capacity: Figure-1 depicts the optimized scheme for irrigation located 10m away from the water wheel, which was used for growing eggplants, tomatoes, and peppers. The optimized scheme included 1.5 hectares for tomatoes, 1.15 hectares for eggplants, and 1.5 hectares for peppers, which resulted in a maximum value of PhP838,816.12 in net income. The results showed that the highest net income of PhP1,032,595.81 was achieved by planting 3.88 hectares of tomatoes, while the lowest net income of PhP401,896.56 was recorded in planting 4.4 hectares of eggplants. Moreover, planting 4.2 hectares of pepper with a water demand of 156.65m^3/day resulted in a net income of PhP870,690.84.

Figure-2 illustrates the most efficient irrigation plan for eggplant, tomato, and pepper crops, which are located 100m away from the water wheel. The optimized scheme recommends planting 0.8ha of tomato, 0.38ha of eggplant, and 0.8ha of pepper, generating a maximum net income of PhP378,313.19. Conversely, if 0.6ha of tomato, 0.7ha of eggplant, and 0.7ha of pepper were planted, the lowest net income of PhP315,312 would be obtained. Additionally, planting 1.8 hectares of tomatoes, 2.12 hectares of eggplants and pepper produced net income of PhP429,589.55, PhP59,726.66, and PhP424,367.22. respectively.

Figure-3 illustrates the optimized scheme for irrigation of eggplant, tomato, and pepper, located 200 meters away from the water wheel. The optimized scheme resulted in a maximum net income of PhP147,752.10, with 0.45 hectares allocated for tomato, 0.22 hectares for eggplant, and 0.45 hectares for pepper. In addition, a single cropping scheme was resulted the highest net income of PhP151,228.48 was achieved when 1.0 hectare was planted with tomatoes, while the lowest net income of PhP44,397.28 was obtained from 1.2 hectares of eggplant. On the other hand, planting pepper on 2.09 hectares resulted in a net income of PhP194,416.45.

Table-1: Input data for optimization.

Particulars	Water wheel capacity (m^3/hr)											
	4.63 (m^3/hr)			3.14 (m^3/hr)			1.78 (m^3/hr)			0.9 (m^3/hr)		
	X_1	X_2	X_3	X_1	X_2	X_3	X_1	X_2	X_3	X_1	X_2	X_3
Ni, yr	2	1	1	2	1	1	2	1	1	2	1	1
Wdi mm/day	5	4.4	4.55	5	4.4	4.55	5	4.4	4.55	5	4.4	4.55
Ws (m^3/day	156.56	156.56	156.56	75.36	75.36	75.36	42.72	42.72	42.72	21.6	21.6	21.6
Ypi, t/ha	25	18.4	15	25	18.4	15	25	18.4	15	25	18.4	15
Cost Php/ha	117,031	92,915.25	151,962	135,078	108,796.21	168,385	178,634	147,125.31	208,020	276,398	233,157.53	296,985
Gross Income, PhP/ha	250,000	184,000	375,000	250,000	184,000	375,000	250,000	184,000	375,000	250,000	184,000	375,000
Net Income, PhP/yr	265,937	91,085	223,038	229,844	75,204	206,615	142,732	36,875	166,980	-52,795	-49,158	78,015

X1, tomato, X2, eggplant, X3, Sweet pepper.

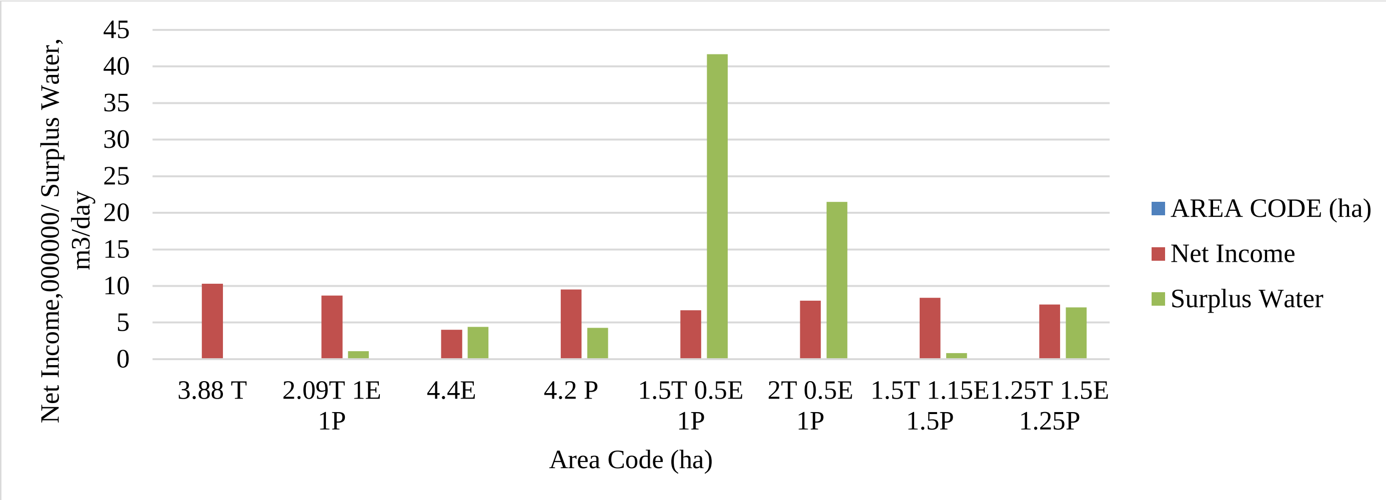

Figure-1: Optimized scheme of 4.63m^3/hr pumping capacity.

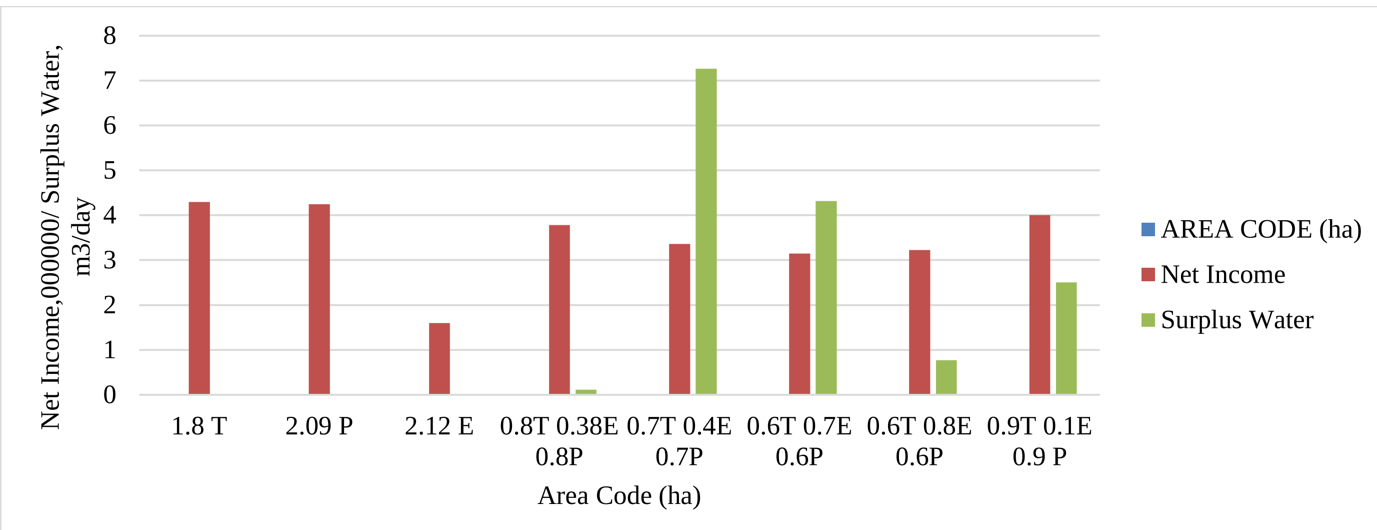

Figure-2: Optimized scheme of 3.16m^3/hr pumping capacity.

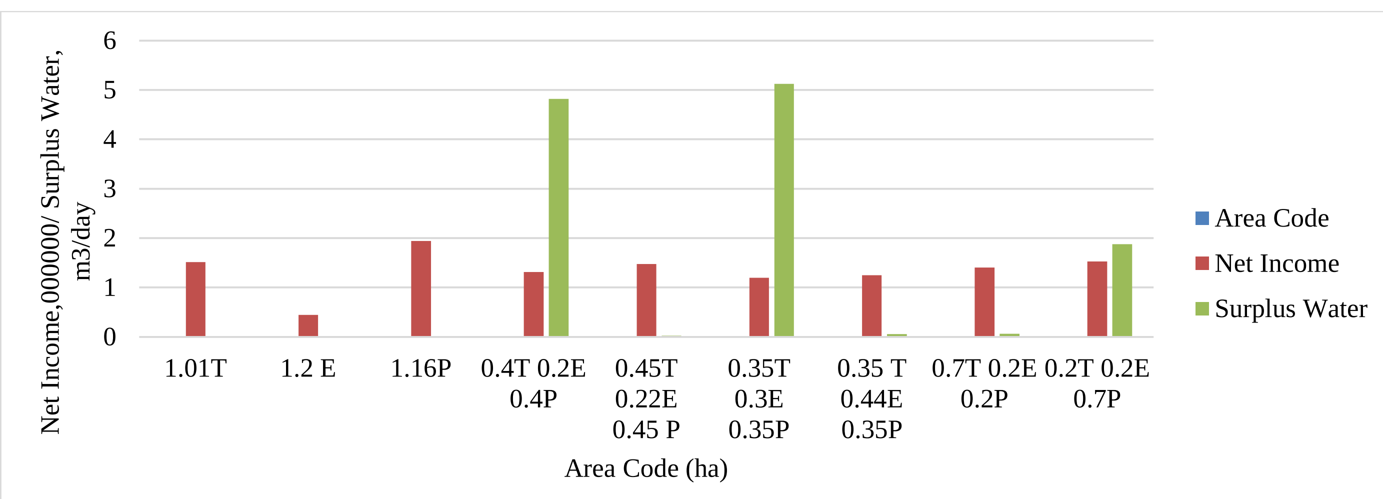

Figure-3: Optimized scheme of 1.78m^3/hr pumping capacity.

The objective function is Maximize: Y =-52,795.39 X_1 + -49,157.5 X_2 + 78,014.57 X_3 with Subject to: (50 X_1 + 44 X_2 + 45.5 X_3) *0.8064 < 21.60. According to the maximization equation, it was assumed that the optimization should result in a positive area in hectares for pepper cultivation. However, the profit for two crops was negative, which was primarily due to the high unit cost of water from the water wheel.

Economic viability of using the system: The total investment cost of the system was PhP103,983.60, PhP107, 483.60, PhP112, 523.60, and PhP115,043.60 for distances of 10m, 100m, 200m, and 300m from the water wheel, respectively. This cost included the water wheel and drip irrigation system. The system operated 24 hours a day, 167 days a year. Table-3 provides an economic summary of the system's usage. Diversification cropping from 10m, 100m, and 200m away from the water wheel would result in payback periods of 0.12, 0.27, and 0.76 years, respectively. The payback period decreased as the distance from the water source increased, due to the low pumping capacity and high cost of pumping water. The returns on investment were 706.68%, 272.46%, and 31.31% for distances of 10m, 100m, and 200m away from the water wheel, respectively. However, a payback period was only positive from 10m to 200m set up, with net incomes of PhP838,816.12 and PhP147,752.10, respectively for planting single crop. If the drip irrigation system was set up closer to the water wheel or water source, there would be a net gain because of the lowest pumping cost and high pumping capacity. On the other hand, if the system were 300m away from the water source, a loss of profit would occur due to high water costs and low pumping capacity.

Table-2: Summary of economic analysis of using the device.

	Parameters		
	Payback Period, yr	Net Income, PhP	Return of Investment, %
10-m away from the water wheel			
- Optimum Value	0.12	838,816.12	706.68
- Tomato	0.10	1,032,595.81	893.04
- Eggplant	0.26	401,896.56	286.50
Pepper	0.11	951,674.53	815.22
100-m away from the water wheel			
- Optimum Value	0.27	400,333.99	272.46
- Tomato	0.25	429,589.55	299.68
- Eggplant	0.67	159,726.66	48.61
- Pepper	0.25	424,367.22	294.82
200-m away from the water wheel			
- Optimum Value	0.76	147,752.10	31.31
- Tomato	0.74	151,228.48	34.40
- Eggplant	2.53	44,397.29	-60.54
- Pepper	0.58	194,416.45	72.78
300-m away from the water wheel			
- Optimum Value	-	-	-
- Tomato	-	-	-
- Eggplant	-	-	-
- Pepper	2.50	45,926.94	-60.08

Conclusion

The water wheel pump was adjusted to meet a constraint on pumping cost by using a fuel-injected pump. The pump operated based on the principles of a hydrostatic pressure mechanism, which scoops water from the canal as it rotates and discharges it to the distribution pipe. The increase in distance between the water wheel and the drip irrigation setup resulted in lower area and income due to lower pumping capacity and higher pumping cost. After conducting an economic analysis, it was found that the system was financially viable except for the 300-m set-up of drip irrigation. To validate the results of optimization, the optimum area of three crops (0.45 ha for tomato, 0.22ha for eggplant, and 0.45ha for pepper) should be irrigated on a 200-m setup of drip irrigation from the water wheel.

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References

1. International Renewable Energy Agency [IRENA](2016). Solar pumping for irrigation: Improving livelihoods and sustainability. Retrieved from http://www.irena.org.

2. Food and Agriculture Organization of the United Nations [FAO]. (2011). Save and Grow: *A Policy Maker's Guide to the Sustainable Intensification of Smallholder Crop Production.* FAO, Rome. www.fao.org/docrep/014/ i2215e/i2215e.pdf

3. De la Cruz, A.M., & Briones, R.M. (2014). Government Investment in Deep Well Pumps: Some Preliminary Notes for Policy. *Philippine Institute for Development Studies.* No.12. https://dirp4.pids.gov.ph/webportal.

4. Nghi, N. T., Helen F. Gavino, H.F., & Regalado, M J. C. (2015). Optimizing water utilization from a wind pump-drip irrigation system for high value crop production. *International Journal of Geomate,* 8(2), 1293-1299.

5. Ghoneim, A. A. (2006). Design optimization of photovoltaic powered water pumping systems. *Energy Conversion and Management,* 47, 1449–1463.

6. Kumbhar, S., Jagtap D. R., Momin, S., & Shinde G.S. (2016). Review on Experimental Set Up of Drip Irrigation by Using Wind Energy. *International Journal of Trend in Research and Development* 3(2), 205-208.

7. Pande, P.C., Singh, A.K., Ansari, S., Vyas, S.K. & Dave, B.K. (2003). Design development and testing of a solar PV pump-based drip system for orchards. *Renewable Energy, Elsevier, vol. 28(3),* pages 385-396.

8. Bolanos, J.C., Orozco, W.O., & Bhandari, R. (2014). Techno-Economic Feasibility Study of Solar and Wind Based Irrigation Systems in Northern Colombia. *World Sustainability Forum*. Retrieved from http://www. sciforum.net/ conference/wsf-4

9. Hossain, M. A, Hassan, M. S., Mottalib, M. A., & Abdul, S. (2015). Technical and economic feasibility of solar pump irrigations for eco-friendly environments. *Procedia Engineering,* 105, 670 – 678.

10. Kumara, L. (2014). Analysis of floating type water wheel for Pico hydro systems in Sri Lanka. (Master's thesis. Energy Technology). http://www.diva-portal.se/smash/get/ diva2: 808617 /FULLTEXT01.pdf

11. Menke, R., Abraham, E., Parpas, P., & Stoianov, I. (2016). Demonstrating demand response from water distribution system through pump scheduling. *Applied Energy* 170, 377–387.

12. Ibrahim, G.A., Che Haron, C.H., & Azhari, C.H. (2011). Sustainable rural energy: traditional water wheels in Padang (PWW), Indonesia. *International Journal. Renewable Energy Technology,* 2(1), 23–31.

13. Bozhinova, S., Kisliakov, D., Müller, G., Hecht, V., & Schneider, S. (2013). Hydropower converters with head differences below 2.5 m. *Proceedings of the ICE-Energy* 165. https://doi.org/10.1680/ener.11.00037.

14. Quaranta, E. (2018). Stream water wheels as renewable energy supply in flowing water: Theoretical considerations, performance assessment and design recommendations. *Energy for Sustainable Development* 45, 96–109.

15. Johnson, J.; Pride, D. (2010). River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska. Report by Alaska Center for Energy and Power (ACEP). Report for Alaska Energy Authority.

16. Jasa, L., Priyad, A., & Purnomo, M. (2014). An Alternative Model of Overshot Waterwheel Based on a Tracking Nozzle Angle Technique for Hydropower Converter. *International Journal of Renewable Energy Research,* 4(4), 1013-1019.

17. Dutta, A. K., Shrestha, B., Shahi, J., Chaudhary, V. K., &Pratisthit, L S. (2016). Re-design and Optimization of Traditional Undershot Wheel using High Density Polyethylene (HDPE) Blades. *Proceedings of the International Symposium on Current Research in Hydraulic Turbines*. https://pdfs.semanticscholar.org.pdf.

18. Thompson, P.L., Milonova, S., Reha, M., Mased, F., & Tromble, I. (2011). Coil Pump Design for a Community Fountain in Zambia. *International Journal for Service Learning in Engineering* 6(1), 33-45.

19. Naegel, L.C.A. Real, J.G. & Mazaredo, A.M., (1991). Designing a spiral pump for irrigation. *Waterlines*, 10(2). https://www.researchgate.net/publication/23355.

20. Collado, J. (2015). Design, Fabrication, and Evaluation of Spiral Paddled Type Water Wheel. (Undergraduate thesis, Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, Philippines).

21. Department of Agriculture, Region 2. [DA RO2]. (2017). High Value Crops Development Program. https://cagayanvalley.da.gov.ph/high-value-crops-iec-materials.

22. Maghirang R.G, Guevarra L.D., & Rodulfo G.S. (2009). Vegetable Production Guide. University of the Philippines Los Baños, College, Laguna, Philippines. Retrieved from http. // pcarrd.dost.gov.ph

23. Tzimopoulos & Ginidi (2005). Optimized Aquifer Management, Using Linear Programming. An Application to the Agia Varvara Aquifer, Drama, Greece. *Global NEST Journal*, 7(3), 395-404.

24. Obi, L. E. (2017). Linear Programming as a Tool for Water Resources Management. *International Journal of Constructive Research in Civil Engineering*, 3(4), 30-47.