Title	DEVELOPMENT AND INTRODUCTION OF A PICO-HYDRO SYSTEM IN SOUTHERN TANZANIA
Author(s)	OKAMURA, Teppei; KUROSAKI, Ryugo; ITANI, Juichi; TAKANO, Masao
Citation	African Study Monographs (2015), 36(2): 117-137
Issue Date	2015-06
URL	http://dx.doi.org/10.14989/200272
Right	
Type	Departmental Bulletin Paper
Textversion	publisher

African Study Monographs, 36 (2): 117–137, June 2015

DEVELOPMENT AND INTRODUCTION OF A PICO-HYDRO SYSTEM IN SOUTHERN TANZANIA

Teppei OKAMURA
Graduate School of Environmental Studies, Nagoya University
Ryugo KUROSAKI
Faculty of Education, Fukuoka University of Education
Juichi ITANI
Graduate School of Asian and African Area Studies, Kyoto University
Masao TAKANO
Graduate School of Environmental Studies, Nagoya University

ABSTRACT The demand for electricity has rapidly risen in rural Tanzania due to the spread of mobile phones. In a rural village in southern Tanzania, we collaborated with a group of villagers to develop a pico-hydro system with a screw turbine and introduced it to a flat plateau with a low water head. The power generation system was designed to take advantage of the fluvial environment and gentle slopes to counteract the drastic changes in water level that can occur throughout Africa. The project began in 2010 with a pico-hydro system using a traditional Japanese screw turbine, resulting in successful power generation in 2012. This study clarified key considerations in developing a community-based pico-hydro system. Low cost, locally sourced materials and equipment are advantageous. A lightweight screw turbine power generation system is transportable to meet changing water levels. Easy reproduction and/or modification can meet changing needs. The proposed system could provide stable electrical power for lights and mobile phones. Additionally, the cooperative exchange promoted by the project inspired the local people to create their own environmental groups to take on activities that supported sustainable natural resource use.

Key Words: Low water head; Flat plateau; Pico-hydro; Rural electrification; Screw turbine; Tanzania.

BACKGROUND AND OBJECTIVE

In Tanzania, only 5.3% of the rural population uses electricity, although power grids have grown yearly and currently available to 17% of the overall population (NBS, 2011). Off-grid electrification has been introduced by the electric power company (Ilskog et al., 2005) in areas without access to the power grid. Additionally, some small power generation systems were constructed with the assistance of the Rural Energy Agency (REA), a government organization. However, these initiatives have only just begun, and progress in providing electricity to rural communities has been slow.

The benefits of rural electrification can range from productivity, education, health care, economic opportunities, information, security, to natural environment and more (IEG, 2008). Kooijman & Clancy (2010) referred to impacts of electrification in rural Tanzania, such as improving the working environment and productivity by installing electricity for lighting, milling grains, and pumping water. The demand for electricity has increased in rural areas, for lighting in houses and schools, powering devices in medical facilities, and charging mobile phones. In particular, the number of mobile phones used in Tanzania exceeds 25 million, which corresponds to 54.5% of the population (CIA, 2012). African village society tends to suppress risk by expanding and maintaining social networks to supplement insufficient public services. For people in rural areas, mobile phones are a vital tool for communication with relatives and friends living far away. Information about the market prices of crops allows farmers in rural areas to better negotiate with crop dealers. In addition, mobile phone companies now have a remittance service that allows users to send cash easily. For example, migrant workers in the city can send money to their families, and parents can send money for school expenses to their children living far away.

Thus, the need to charge mobile phones has placed a new demand on the electricity supply in rural Tanzania. Stable electricity is required in these areas, even if it is small power. Currently, people living in these rural areas with no access to the power grid use diesel-engine generators or photovoltaic (PV) solar panels. According to Ahlborg & Hammar (2012), fuel costs are still a significant obstacle for the diesel off-grid systems, because the price of diesel is exceptionally high in remote areas. PV panels, while requiring no fuel, provide little power during the rainy season. As these systems in rural areas are costly, they are affordable only to the few people taking in a salary, such as primary school teachers. Currently, most mobile phone users in rural areas use charging services provided by PV owners.

Potential energy from wind and biomass from agro-industrial residues have been studied and regarded as possible sources of electric generation (Kainkwa, 2000; Kivaisi & Rubindamayugi, 1996), although these technologies are yet to be practically used in rural areas. The most effective off-grid power alternative to PV generated power would be small-scale hydropower. Small-scale hydropower systems have become available in many developing countries, offering a stable, low-cost power generation (Lahimer et al., 2012).

Recently, pico- and micro-hydro projects have begun in Tanzania by a conglomerate of universities, non-governmental organizations (NGOs), and consulting companies. However, no factory specializes in hydropower systems, and the system components are prohibitively expensive for the local people. In some rural communities, however, groups and/or individuals have developed self-made hydro systems. In many cases, the local inhabitants imitate the hydro-systems set up in churches and construct their own, using materials found in their villages. Particularly, in the Njombe Region, located in the southern highlands of Tanzania, many local projects have installed hydro-stations (Kurosaki et al., 2014). Early hydropower systems commonly use an undershot water wheel powered by a high water head, i.e., height of the waterfall. To minimize production costs, the villagers collected and utilized scrap materials to build the waterwheel at a local factory. Smith (1994) highlighted how using local equipment and skills is essential for sustainable and commercially viable projects in the long term. The small hydro-systems manufactured with local technologies may be reproducible in other rural areas. However, most of the existing hydro-stations have been installed only in mountainous regions, due to the requirements for a high water head and stable water flow for undershot waterwheel operation. A hydro-station is generally set on a concrete base in a stream in which the water flow is controlled. Installment in flat terrain conditions can be challenging for hydro-systems, due to the low head and drastic fluctuation in water levels that occur throughout the year in Africa. Even if the power generation is low, these installations are important to the villagers, significantly affecting their everyday lives and economic opportunities.

In an effort to promote sustainable development in rural areas in Africa, we focused on the potential of hydro power systems. The development of such a system requires that numerous technical barriers be overcome. In this study, we developed a hydro-power generation system for flat terrain conditions. Additional requirements included a low cost, simple technology and portability to adjust the location with changes in water availability. After significant trial and error, we created and installed a pico-hydro system using a traditional Japanese screw-type turbine, and successfully demonstrated electricity generation. The process was documented, and the multiple effects of the hydro-project on the village are discussed in this paper.

An added benefit is that the availability of hydro power may provide the villagers with the incentive to conserve their fluvial environments to retain their water resources (Kurosaki et al., 2014). Recent studies have shown that community-based hydro-projects promote not only technological advances but also cultural and social development of the village (Fulford et al., 2000; Maher et al., 2003; Lahimer et al., 2012). These projects also enhance the local peoples' environmental consciousness, as observed by Kurosaki et al. (2014) who reported that the villagers operating hydro-stations in Njombe Region engaged in afforesting water catchments on their own initiative. As another objective of this study, we focus on the changes in the farmer consciousness for environmental conservation through the implementation of the activities using natural resources.

THE PICO-HYDRO PROJECT

I. Study area

This practical study was implemented in Mfuto Village located 200 km west of Mbeya, the largest city in southern Tanzania (Fig. 1). The villagers are the Nyamwanga people, one of the Bantu peoples, who grow several crops in their indigenous farming system (Itani, 2007). Most of the area consists of plateau terrain, ranging from 1,200 to 1,600 m in elevation. The annual precipitation during the rainy season, November to March, varies from 600 to 900 mm. The area receives little to no rain in the dry season from April to October. However, the Momba River running through the east side of the village does not dry up, due to the large water catchment area provided by woodlands and seasonal swamps. The people rely on the river for their survival, blessed by the river water for

Fig. 1. Location of Mfuto village, Momba district, Mbeya region

domestic use and fish as an important protein source. They grow mainly maize and beans in a slash-and-burn farming system; these crops are a source of food and income.

Under current globalization demands, these farmers have been forced to obtain more cash income to meet their basic needs, education, and medical care. Thus, local farmers that depend on the sale of farm products for cash income have had to expand their farms through woodland clearing, even in the catchment areas. This practice seriously degrades the environment with soil depletion and threatens the subsistence of the villagers. Additionally, the water level of the Momba River during the dry season has gradually decreased over time.

Most villagers in the remote areas outside the electric supply grid use a mobile phone for communication and business. In particular, in the local villages, such as Mfuto, where produce is a major income source, the people increasingly rely on their mobile phones for market information. Mobile phone operation in the village requires electric power generation. Some farmers charge their phone batteries with PV solar panels owned by a few villagers. However, solar generated power is not sufficient, particularly during the rainy season. The only way for the villagers to obtain more electricity at the moment is to purchase the more expensive PV systems.

II. The villagers' group

Several groups have been organized in Mfuto Village in efforts to improve everyday life in the village. One group, consisting of eight members, engaged in several trials to improve agricultural productivity. However, despite the initial excitement, morale soon fell when these activities by the group failed to meet expectations. In an attempt to build on this initial effort, we suggested to this group the implementation of a hydro power generation system for the Momba River. The purpose of the proposed system was to establish a source of electricity, in addition to building group unity and environmental awareness. The hydro project was welcomed by the group, and the work began in 2010.

As a first step, some group members took the opportunity to visit a pico-hydro plant with an undershot waterwheel, created by the local people in the Njombe Region. Based on this design, the Mfuto villagers initiated their own pico-hydro system project. The system configuration was initially implemented with an undershot waterwheel from 2010 to 2011. However, because the undershot waterwheel requires a high water head for fast rotational speed as well as a concrete base for stabilization, the original hydro system design was modified. In 2012 we introduced a traditional Japanese screw turbine, which provided a portable power generation system that was operable under low water head conditions.

The resulting pico-hydro system had five key features: 1) a simple design for easy fabrication, maintenance, and repair by the local villagers, 2) good compatibility with existing village technology, 3) low manufacturing costs using locally available materials, 4) operability with low water head, and 5) a lightweight, portable design.

III. Hollow screw turbine

To satisfy the above requirements, we focused on a hollow screw turbine, used throughout Japan since the 1920s as a power source for agricultural implements. The turbine is usually used for gentle slopes of about 20 degrees, requiring a water head of only tens of centimeters and accepting comparatively large flows. In the earlier screw turbine configurations, the blades were connected directly to a thick shaft, such as that for an Archimedes screw (Müller & Senior, 2009). Hollow screw turbines that have a space between the shaft and blades were designed to reduce the weight of the turbine (Fig. 2). Farmers could transport the light turbine anywhere. The hollow turbine has a lower efficiency, due, in part, to large water loss through the hollow space. However, this loss can be used to regulate

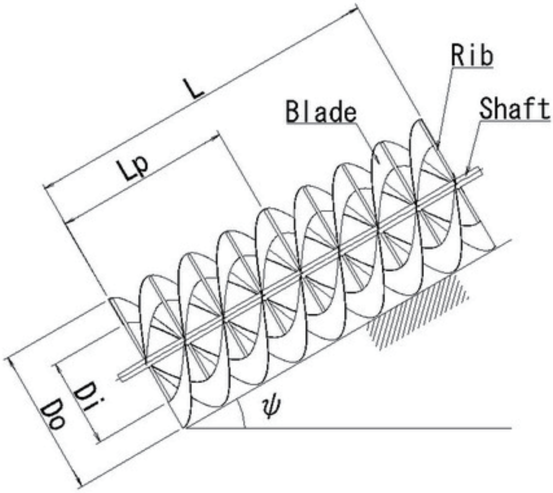

Fig. 2. Hollow screw turbine

the power output against large changes in river flow. Thus, the hollow screw turbine is more suitable to the conditions in Africa where it is difficult to control water head and flow.

METHODS

Important project milestones, dates, and key participants are listed in Table 1. The project consisted of seven steps: (1) market research on materials and their availability, (2) site survey, (3) design, (4) manufacturing, (5) installation, (6) testing, and (7) monitoring. Market research and manufacturing were conducted in a workshop in Mbeya Town with two members of the group. The other steps were carried out by all of the group members in the village.

Seasonal changes in the water level of the Momba River were monitored with a water level gauge (HOBO Water Level Logger -U20L-01). The profile of the riverbed was documented. We researched the mechanical skills of the villagers, as well as the locally available materials and their prices. Specifically, shops dealing with steel, mechanical parts, electrical parts, scrap car parts, machinery, construction components, bicycles, motorbikes, and other hardware were searched throughout the community in an attempt to locate new and used materials for the system hardware. The prices for the material and components varied, depending on availability and subsequent negotiation.

Table 1. Key pico-hydro project milestones and the number of participants

Date		Place	Work	Number of key participants		
				Villager	Researcher	Engineer
2010 Sep – 2011 Aug		Mfuto	Measuring water level	0	1	0
2011	Dec. 19	Mbeya	Making turbine frame	2	2	1
2012	Aug. 9	Mbeya	Market survey	2	3	0
	Aug. 11	Mfuto	Site survey	8	3	0
	Aug. 12, 13	Mfuto	System design	0	1	0
	Aug. 15, 16	Mbeya	Market survey	2	3	0
	Aug. 16, 17	Mbeya	System design	0	1	0
	Aug. 16, 17	Mbeya	Making turbine	2	2	0
	Aug. 18, 19	Mbeya	Making housing	0	3	1
	Aug. 20, 21	Mbeya	Making transmission	0	3	2
	Aug. 30	Mfuto	Painting	8	3	0
	Aug. 30	Mfuto	Assembling	8	3	0
	Aug. 31	Mfuto	Installation	8	3	0
	Sep. 1	Mfuto	Running tests	8	2	0

The pico-hydro system was designed taking into consideration weight, material price, ease of production, and maintenance after installation. The system was constructed at a local workshop equipped with welding and drill press machines, a lathe, an angle cutter, and a grinder, among others. Finally, the pico-hydro system was installed in the Momba River and tested.

Since the installation in 2011, we have educated the group members on how to handle the electric devices and discussed potential mechanical problems, environmental suitability, and socio-economic effects. At the same time, the effect of the hydro project on other activities was observed and documented.

RESULTS

I. Site survey

The Momba River runs east of the Mfuto Village into inland Lake Rukwa and has a flow of at least several hundred liters per second, even during the dry season. The Momba River has several waterfalls of about 0.5 m in height. It was difficult to dig a canal to secure the water head, due to the rock bed covering the riverside. During the rainy season, the water level increases by about 3 m (Fig. 3), and the water flow expands to about 30 m in width. Given this variation, the location of the pico-hydro system was chosen where the water level was appropriate in both rainy and dry seasons. In addition, the bottom of the pico-hydro system was adjusted to fit the surface of the riverbed.

The availability of industrial technology in the village was low. Few machinery and tools exist in Mfuto to maintain the system, because almost all of the work in the village is done by hand. However, villagers use bicycles daily and are well versed in maintaining bicycles (i.e., alignment and part replacement and repair,

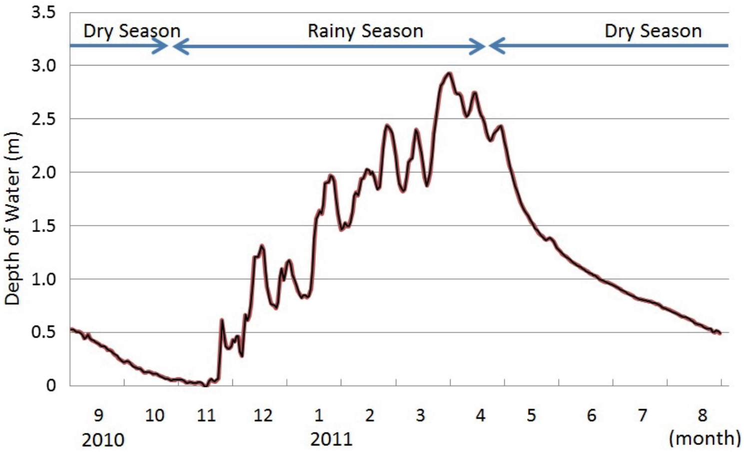

Fig. 3. Seasonal changes in the water level of the Momba River

such as that related to wheels, bearings, sprockets, and chains).

Before the pico-hydro project, the villagers had rarely used electronic products, except for those that run on dry-cell batteries. However, since mobile phone use became available, there has been an increasing demand for electric power in the village. Although the villagers were using kerosene lamps and electric torches with dry-cell batteries as lighting sources, the cost of fuel and batteries were economic burdens for them, and the lighting was insufficient. Thus, the villagers were looking for brighter lighting with a low operating cost.

II. Local market survey

Various materials, such as general steel, machinery parts, and scrap metal, were found in local markets to manufacture the pico-hydro system (Table 2). New steel angles for the frame and thin steel plates (thickness: <6 mm) for the bottom cover could be found in hardware shops. New load-bearing parts and other machinery parts, such as pulleys and sprockets, were also available.

Other components of the hydro system were self-made, or used car parts gathered from scrap dealers. All of the scrap car parts are recycled as spare parts in Tanzania. An alternator and a drive shaft for cars were obtained at low cost from scrap shops that stand side-by-side in the town. Drive shafts could substitute as transmission shafts (diameter, 30 mm). Thick steel plates and pulleys, varying in diameter from 80 to 160 mm, were also available from parts and scrap shops.

Recently, motorcycles made in China have become widespread in Africa. New spare parts for these bikes are available at reasonable prices. The sprockets of motorbikes and bicycle wheels are compatible for use as transmission parts with chains and V-belts.

Generators driven by petrol engines with an output that exceeds 1 kW could be obtained from machinery shops. Although these generators can be used for large-scale hydropower plants, they were too large for our pico-hydro system. Generators with an output of less than 1 kW from car alternators were readily available. Only the reinforced polyester resin, used for the screw blades, was purchased in Dar es Salaam, the largest city in Tanzania.

Many of the electrical components were taken from used electronic products. Basic parts, such as diodes and electrolytic capacitors, were available as new and unused parts. Low cost, low power consuming, and long duration light-emitting diodes were available. To minimize the cost of the pico-hydro system, we used parts with high availability, such as those used in construction and as car parts, and combined these with motorcycle parts.

Table 2. Materials and parts of the pico-hydro system obtained from the market in Mbeya

	New	Used	Unavailable or very expensive
Steel materials	Steel angle Steel plate (<6 mm) Iron rod	Car scrap Steel plate (≥6 mm) Steel angle	Steel bar (>10 mm)
Machinery parts	Car parts Motorcycle parts Bearing unit Bolt V-belt	Small pulley Car parts V-belt	Large pulley Industrial sprockets
Generators	Synchronous generator (>1 kW)	Hub dynamo Car alternator	Synchronous generator (<1 kW)
Electric parts	Motorcycle battery (6 V) Car battery (12 V) Diodes Electrolytic capacitors		

III. Design and manufacture

The pico-hydro system consisted of a turbine, transmission, generator, and housing. The composition of the pico-hydro system is listed in Table 3.

Table 3. Composition of the pico-hydro system

	Materials
Turbine	Steel pipe Steel mesh Polyester resin Bearing unit
Housing	Steel angle Steel plate Steel drum
Transmission	Motorcycle sprocket and chains Car shaft Steel angle Bearing unit
Generator	Car alternator

1. Turbine

The four blades of the screw turbine were fixed on ribs welded to the shaft, as shown in Fig. 4. The screw turbine had an outer diameter of 550 mm, an inner diameter of 210 mm, and a pitch of 1,000 mm (Fig. 2), where pitch is the length of the shaft where the blade singly winds around the shaft. The most challenging of making the turbine was creating a curved surface for the spiral blades. In addition to being lightweight, the turbine must be strong. A blade made with steel mesh used in poultry farming, steel bars, and a steel pipe for a

Fig. 4. Blades and housing of the screw turbine

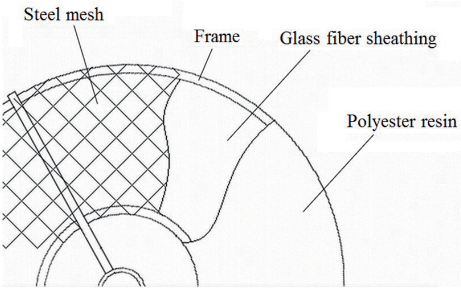

Fig. 5. Layer structure of the blade

rotation axis, was reinforced with polyester resin (Fig. 5). The inner and outer spiral edging of the rotary screw blades were composed of thick steel wire (diameter: 8 mm). The edging was welded to the fixed steel ribs positioned every quarter of a pitch along the steel pipe. This final design, shaped by the inner and outer wires, was developed at the Fushimi Technical High School of Japan. The steel mesh was tied with a thin wire to the inner and outer spirals. Glass fiber sheathing was attached to the mesh with wire, using resin plastered onto the sheathing (Fig. 5). The shaft (rotary axis) made with steel pipe (diameter: 48.6 mm), was welded thickly at the point where the bearing was attached, while shaved thin to fit the diameter at the bearing unit hole (diameter: 50 mm).

2. Transmission

The sprocket of a motorcycle, a chain belt, and a car shaft were used for rotational transmission to increase the rotational speed (Fig. 6). Circular plate adapters were attached to the sprockets and the shaft by bolts (Fig. 7). These adapters had the function of adapting the holes to the diameter of the shaft, aligning the rotational axis of the sprocket for torque transmission, as opposed to the use of a machined key groove.

The rotational speed of the screw turbine was set at 50 rpm to suppress vibrations during operation. The output voltage of the generator usually settled

Fig. 6. Transmission of the screw turbine

Fig. 7. Sprocket attached to the shaft via an adapter

to a somewhat higher voltage than the open-circuit voltage of the battery when connected. The alternator was designed to output about 13.5 V at 1,200 rpm. However, using 6 V batteries, the rotational speed of the generator was believed to be smaller, closer to 800 rpm. Accordingly, the transmission ratio of the screw turbine system was determined to be 16, using three sets of motorcycle sprockets and chains (Table 4).

Table 4. Transmission ratio of the pico-hydro system

Transmission ratio	First	1.47
	Second	3.29
	Third	3.29
	Total	15.91
Materials	Motorcycle sprockets and chains	

3. Generator

An alternator removed from a scrapped car, widely available in Tanzania, was used as the generator. Car alternators are designed to generate 100–200 W of power at comparably low rotational speeds (<1,200 rpm). Thus, car alternators are suitable for pico-hydro systems with open waterwheels, which run at low rotational speeds and have a low power output. Car alternators are synchronous generators with electromagnets, i.e., rotor coils magnetized by electric current, where the output comes out from the stator coils.

An alternator has a regulator to adjust the electric current to prevent oversupply. Most of the regulators from the scrap-parts shops were broken. However, a regulator was not required for the pico-hydro system, because the electric current was directly supplied from the battery at the start of operation (Fig. 8). Additionally, an alternator with a broken regulator is about one-tenth the price of a normal one in Tanzania, thus, providing a low-cost component for the pico-hydro system.

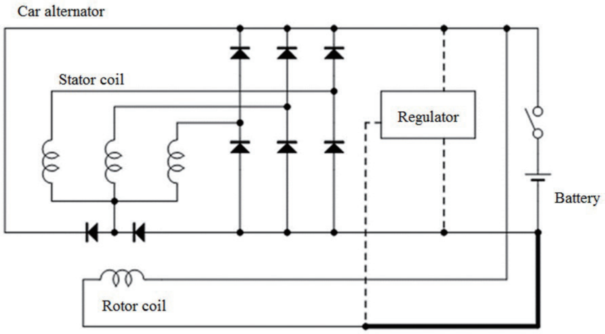

Fig. 8. Schematic diagram of the circuit connecting the alternator and battery
The dotted lines correspond to the points where the lines are disconnected and the rotor coil is connected (bold line).

The electricity was stored in motorcycle batteries, which are cheap and portable. The generated electric current was rectified in the circuit using a built-in alternator, and the resulting direct current charged the batteries.

4. Housing

The screw turbine, generator, and transmission lines were integrated into a housing component for portability. The housing was framed with steel angles. The bottom of the housing was covered with a gutter made from a half-cut drum, for turbine protection and water-flow accumulation (Fig. 9). Reinforcing rods of variable length were positioned at the four corners of the frame and pinned by bolts to arbitrarily adjust the turbine angle with varying slope. Additionally, bicycle wheels could be attached to the sides of the housing if the turbine needed to be moved over long distances. For security, the entire system was covered with an iron net and panel, and a fence was placed in front of the turbine. The alternator was connected to the batteries via an electric transmission cable connected to a charge box set on the riverbank.

Fig. 9. Screw turbine pico-hydro system setup

IV. Installation

The screw turbine was placed in a section of the river with a strong and steady current (Fig. 9). A small weir was built using sand bags to concentrate the water flow to the turbine. The angle was adjusted to make the turbine parallel with respect to the direction of water flow. The inclination of the screw turbine was 15 degrees. The system could be stopped as needed for maintenance or other work, simply by removing a sand bag from in front of the housing to allow the water to flow out from under the gutter.

The pico-hydro system must be sufficiently light in weight to be carried by hand to reset the system according to the water level. The weight of the pico-hydro system components is given in Table 5. The total weight of the screw turbine system was 90.7 kg; three adult men could move the turbine. The light weight of the system facilitated installation work, such as rod adjustment and location adjustment for optimal flow.

Table 5. Weight of the pico-hydro system components

Component	Weight [kg]
Turbine, waterwheel	28.0
Housing	35.6
Transmission	27.1
Total	90.7

V. Test operation

The screw turbine system was tested with lead-acid type motorcycle batteries (6 V) with a charge current of 0.6 A and a capacity of 3–12 Ah. In the test, the electric current and rotational speed of the water wheel were measured as a function of the number of batteries connected in parallel for the system, which varied from one to eight batteries. When resistor loads were introduced, the rotor coils were separated from the outer coils and connected to the battery; only the generated current flowed into the resistors. To test the metal-clad resistors, the battery voltage, electric current of the rotor coils, and the resistor voltage were measured.

The test results are shown in Table 6. The screw turbine system produced about 20 W constantly. With the batteries connected, the maximum output was 25.7 W. The rotational speed did not exceed the rotational speed specified for the alternator by the manufacturer. The system had no trouble operating at a maximum rotational speed of 63.1 rpm without a load.

The output power was higher at lower resistance in the test with metal-clad resistors (Fig. 10). The highest voltage produced with this system was 10 V for the highest resistance. However, the torque load on the screw turbine was low, and the turbine was almost idling, because the load current was low at high resistance. In contrast, when the turbine rotated slowly with low resistance, the amount of water inside the turbine increased and the blades were pushed by the flow. The output power was high. When eight batteries were connected, the power reached 25.6 W (Table 6); the equivalent resistance was 2.7 Ω.

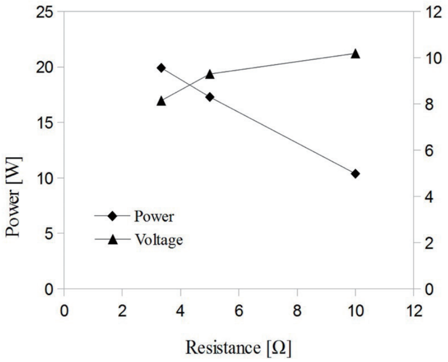

Fig. 10. Output of the experiment with a load of metal-clad resistors

Table 6. Operational test results

Number of batteries	Voltage [V]	Current [A]	Power [W]	Rotation speed of turbine [rpm]	Rotation speed of generator [rpm]
0	0.00	0.0	0.0	63.1	1009.2
2	8.00	3.0	24.0	48.9	781.3
3	7.90	3.0	23.7	48.9	781.3
4	8.15	2.9	23.6	48.9	781.3
5	8.30	3.1	25.7	50.9	813.8
6	8.20	3.1	25.4	51.9	830.1
7	8.25	3.1	25.6	51.6	824.7
8	8.25	3.1	25.6	51.9	830.1

The number of electric goods powered is shown in Table 7, for a constant power output of 25 W with a charge–discharge efficiency of 80%. It was assumed that 2 W LED light bulbs are used for an average of 3 h per day, and that 4 Wh are required to charge a mobile phone battery daily. Thus, power for 80 LED light bulbs or 120 charges of a mobile phone would be available daily with this output. The power output is sufficient to supply electricity to 48 households, if each household used one LED lighting and charged one mobile phone, daily.

Table 7. Output of the pico-hydro system and potential number of electric items powered with assumed charge-discharge efficiency of 80%

Output [W]	25
Total daily energy for electric items [Wh]	480
Number of LED bulbs (6Wh/d) lighted per night	80
Number of mobile phone charged (4Wh/d) per day	120

VI. Cost

The material and labor costs for each component of the system are shown in Table 8. The total manufacturing cost was $459.9 United States dollars (USD), including the material cost of $304.3 USD (66%). Using scrap material and simplifying the structure, the manufacturing cost could be suppressed further. The frame of the turbine was made with thick wire and the steel pipe appeared to be strong enough to withstand the water pressure. The fiber-reinforced plastic (FRP) used for the blades of the screw turbine was the only component that was not widely available. However, cheaper and more accessible materials may be applicable.

It took a total of 92 person-days to introduce the screw turbine pico-hydro system (Fig. 11). The bulk of these (82 person-days) involved unskilled work, performed by both the villagers and researchers. The remaining 10 person-days included the design created by the researcher and several manufacturing processes conducted by engineers in Mbeya, such as welding and machining that required

Table 8. Cost of the pico-hydro system in united states dollars (USD)

Material costs	Turbine	72.5
	Housing	41.8
	Transmission	153.0
	Water control	7.0
	Cover	30.0
Subtotal		304.3
Labor costs	Turbine	22.2
	Housing	44.5
	Transmission	88.9
Subtotal		155.6
Total		459.9

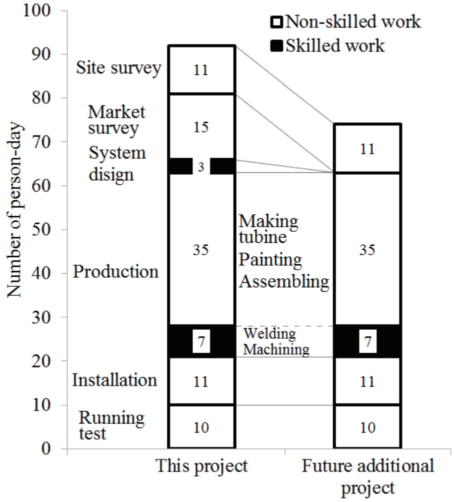

Fig. 11. Production requirements for this project and for additional project

skilled labor. Only 7 person-days of the engineers' work counted as labor cost, with a price of about $22 USD per person-day. The labor cost for the screw turbine was $155.6 USD. Because market research and design has already been completed and the system components determined, manufacturing the turbine system was estimated to require only 74 person-days, which including 7 person-days for skilled welding and machining.

The 48 families can share the cost for the screw turbine system, $459.9 USD, where every household uses one LED lighting and charges one mobile phone daily. Each family would contribute $9.6 USD for the system. This cost should be affordable for the village inhabitants. Moreover, the investment can be recouped by charging mobile phones 48 times, because currently a charging service costs 20 cents a charge. Recouping the cost takes about 11 months if each family charges a mobile phone once per week.

VII. Running the system

The life span of the system should last more than twenty years if exhausted parts are replaced. Parts requiring replacement would be sprockets, chains, bearings and the alternator. Small sprockets may last for about 6 months, and large sprockets and chains last about 1 year if the pico-hydro system runs all the time, although the duration largely depends on the running condition. Bearings and the alternator may last for several years or more. A small sprocket, a large sprocket, and a chain cost \$1.3, \$5.1 and \$5.7 USD each. A bearing unit and an alternator cost \$21.6 and \$44.5 USD each. Villagers need to pay these additional costs upon replacement.

Daily maintenance for the system is debris removal. The screw turbine tolerates small debris in water, and leaves, wood pieces, and most other floating and suspended matters pass through the rotating blades. However long twigs and vines could be caught in the system and they must be removed once in a few days. Other maintenance required is adjusting the transmission and grease up. These works are required once in a few months.

VIII. Changes in villager consciousness of environmental degradation

With rapid economic growth in Tanzania, inflation and urban–rural disparity have pressured village life in rural areas. The villagers who have only a few options for cash income have had to expand their farms via clear-cutting for crop and charcoal production, at the expense of the area’s natural resources. This new practice has seriously degraded the woodland environment and threatened the water supply. In conjunction with the pico-hydro project, we attempted to increase environmental awareness for the effects of deforestation among the villagers of the project group.

During the pico-hydro installation process, the villagers expended much effort to secure enough water flow to the turbine during the dry season when the water levels were low. An older group member, who participated as an advisor in the group meetings, emphasized the impact of rampant deforestation that may have resulted in the chronic lowering of the water level. The other members of the group, hearing this, agreed. The discussion became a turning point in their commitment to environmental protection. By the following year, an environmental committee had been organized to focus on these issues. We also advised the group on the economic and ecological advantage of afforestation, and offered seeds of several tree species for rehabilitation of a multi-purpose forest, including bamboo, banana, and other fruit trees, and timber trees. They prepared nurseries in the mid dry season and planted the seedlings around their houses in the rainy season. A cooperative framework was established in the group through these activities.

DISCUSSION

Three key accomplishments of this study are summarized in the following.

1) Hydro stations with hollow screw turbines in Africa

Undershot waterwheel hydro systems have been constructed in many areas of Tanzania since 2000, when the government allowed individual power generation. However, general-use hydro stations have been installed only in mountainous areas with steep slopes, due to the requirement of a high water head for fast rotational speeds. Previous studies have pointed out the mechanical effectiveness of the screw turbine, which can produce power from flow at varying slopes (Müller & Senior, 2009; Shimomura & Takano, 2013). The screw turbine has a higher rotational speed, than general waterwheels, and is suitable for creating pico-hydro generation systems (Okamura et al, 2011). These advantages have led to successful power generation in flat areas with only low water heads, indicating the wide range of applications for this approach.

A hollowed-type screw turbine was popular in Japan in the early 20th century, due to its light weight and portability (Tanaka, 1990). The farmers in Japan required power generation for farm work in flat paddy fields. Compact, simple, lightweight and easy installation without a concrete base made the screw turbine the preferred power generation system. For these reasons, we applied the screw turbine system in Africa where the water level drastically fluctuates between the dry and rainy seasons. Additionally, the screw turbine allows fish and suspended matter in the flow to pass through (Kibel, 2007). The eco-friendly benefits provided by this power generation system are especially important to the local people who rely on the river for their livelihood, e.g., food, crop production for market, and fishing. Thus, the hollow screw turbine is functionally suitable to the rural conditions of Africa.

2) Technical feasibility of fabricating and running the hydro station in Tanzania

Taking into account the current technology and economy in rural areas of Africa, the simple pico-hydro system demonstrated above provides great potential for its wide dissemination. The parts for the hydro system comprised used or scrap materials. The simple design allows for easy construction, installation, and maintenance by the local people, due to their familiarity with bicycle components, such as chains and sprockets. Moreover, bicycle wheels could be attached to the frame of the system, allowing long-distance transport for repair or site change according to water levels. The pico-hydro system is therefore maintainable, and the parts can be replaced and repaired easily by the local villagers.

Using consumer-product parts also improved the portability of the system, because these parts have functional shapes and are light in weight. Car alternators with broken regulators were substituted as low-power generators not available in Mbeya, which significantly reduced the material costs. Tanzanian engineers would be able to replicate the system, because the system components are thoroughly visible without dismantling the entire system. We used FRP was to make the blades for the turbine. However, this material could be substituted if it became prohibitively expensive or unavailable in rural Tanzania. If the system does not need large torque, material other than FRP with lower durability, such as plastic fertilizer bags, may be available.

Future improvements to the system should focus on increasing the power output and further reducing the cost. In the test run, the incline was only 15 degrees, and the river flow escaped from the sides. The flow taken into the system was estimated at about 60 liters per second from the rotational speed of the turbine and the water level in the system. Higher output is possible if the turbine is set on a steeper slope and allowed for more flow. The system is applicable for up to 100 W generation. However, above 100 W, the system would need to be redesigned to include a new, more robust generator with a larger turbine.

Currently the system services 8 families, fully charging batteries by running the system only during daytime. However, the system needs to charge batteries for 24 hours a day to produce electricity to 48 families as discussed above. However, charging during night time should be avoided to reduce risks, such as mistaking the connection of cables when adjusting the system. What is better is to set the batteries early in the evening to collect them next morning. One battery with capacity of 6 Ah can be fully charged in 2 hours with the output from the system of about 3 A. For example, villagers set 4 empty batteries at 8:00 am and charge for 8 hours. Then villagers set 8 empty batteries instead of 4 at 4:00 pm. These 8 batteries would be fully charge when left until 8:00 am the next morning by charging 16 hours. This way, 12 batteries can be charged in 24 hours, and it takes 4 days for 48 families to charge batteries taking turns.

3) Positive windfall from the hydro project on rural development

As mentioned above, the purpose of the pico-hydro project was to meet the growing need for power generation by the local people in rural communities and to provide greater awareness of the environmental issues as they related to the current farming practices and deforestation. As a result, the project villager group began to plant trees to replace those felled by clear-cutting. This showed that the villagers were committed to improving their lives by becoming more environmentally responsible. With Africa facing serious deforestation, this was a promising step towards coping with and remediating the environmental degradation.

Before the hydro project began, the villager group had already engaged in several activities to increase agricultural production and cash income. However, benefits from these practices never came to fruition, due to a lack of consensus among the group members on basic principles for these activities. However, the successful experience with the hydro project inspired greater cooperation among the group to advance other efforts. Thus, the pico-hydro station can function as a symbol of rural development.

CONCLUSION

According to an officer in the Ministry of Water, no hydro generation project has ever been implemented in the Mbeya Region. This study is the first record of electric generation by hydropower. Our practical study clarified the workability of screw-type pico-hydro systems in flat areas and the economic and technical feasibility of manufacturing such a system. The hydro system described and its implementation should be reproducible, given several key components: (1) the use of a hollow-screw turbine, (2) the collection and use of local materials, (3) manufacturing the system using local technology, and (4) the installation in flat areas. The system produced power to supply electricity to meet the villagers' basic needs, which were domestic lighting and charging of mobile phones. The simple design can be reproduced easily for other pico-hydro projects, and the practices reveal the potential for widespread dissemination, complementing the PV solar panels currently used to generate power during the dry season. The pico-hydro power using a screw turbine should be applicable to other flat areas in Africa with river access.

Although the system requires some improvements, it provides a good basis for future development, with a multilateral impact on the local society and economy over the long term. The sustainability and long-term effects of the pico-hydro system should be assessed, by researching the technical aspects, such as management and modification of the systems by the villagers.

On the other hand, we should pay attention to the impact of the hydro project on the environmental consciousness of the local people. In the hydro project, group members repeatedly discussed the reasons behind the lower water levels in the dry season year by year. They agreed that the enlargement of farms caused the large fluctuation in water levels in a year, and decided to restore vegetation. Charging mobile phones and domestic lighting made possible after the success of electric generation accelerated activities for environmental conservation. Afforestation became more than an environmental issue for the future, affecting current livelihoods. The villagers have planted various multi-purpose trees. It is noteworthy that the farmers commenced to plant trees on their initiative. Pressure on the natural vegetation may decrease through the cyclic use of the artificial forests. The hydro project functioned as a tool to combine villager needs and environmental conservation. This study indicates that external technology using available natural resource may have a potential to combine the villagers' current needs and the ecosystem, to promote environmental conservation with farmer initiative. Based on this outcome, we continue to monitor the villagers' conservation activities, while providing technical support as needed.

ACKNOWLEDGEMENTS This study was financed by Grants-in-Aid for Scientific Research (No. 22310151, headed by J. Itani at Kyoto University) from the Japan Society for the Promotion of Science. We would like to thank all of the members of the villagers' group and the people of Mfuto Village for assisting us with this project. We would also like to thank the engineers in the factory in Mbeya for supporting us in the development of the pico-hydro system.

REFERENCES

Ahlborg, H. & L. Hammar 2012. Drivers barriers to rural electrification in Tanzania and Mozambique – Grid extension, off-grid, and renewable energy technologies. *Renewable Energy*, 61: 117–124.

Central Intelligence Agency (CIA) 2012. *Factbook*, Online: https://www.cia.gov/library/publications/the-world-factbook/geos/tz.html (Accessed November 14, 2012)

Fulford, D.J., P. Mosley & A. Gill 2000. Recommendations on the use of micro-hydro power in rural development. *Journal of International Development*, 12: 975–983.

Independent Evaluation Group (IEG) 2008. *The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits*. The World Bank, Washington D.C.

Ilskog, E., B. Kjellstr, M. Gullbergb, M. Katyegac & W. Chambalad 2005. Electrification co-operatives bring new light to rural Tanzania. *Energy Policy*, 33: 1299–1307.

Itani, J. 2007. Effects of socio-economic changes on cultivation systems under customary land tenure in Mbozi District, southern Tanzania. *African Study Monographs*, 34: 57–74.

Kainkwa, R.M.R. 2000. Wind speed pattern and the available wind power at Basotu, Tanzania. *Renewable Energy*, 21: 289–295.

Kibel, P. 2007. *Fish Monitoring and Live Fish Trials. Ritz Atro Archimedes Screw Turbine, River Dart. Phase 1 Report: Live Fish Trials, Smolts, Leading Edge Assessment, Disorientation Study, Outflow Monitoring*. Fishtek Consulting, Devon.

Kivaisi, A.K. & M.S.T. Rubindamayugi 1996. The potential of agro-industrial residues for production of biogas and electricity in Tanzania. *Renewable Energy*, 9: 917–921.

Kooijman-van Dijk, A.L. & J. Clancy 2010. Impacts of electricity access to rural enterprises in Bolivia, Tanzania and Vietnam. *Energy for Sustainable Development*, 14: 14–21.

Kurosaki R., T. Okamura & J. Itani 2014. The current status of pico hydro power systems based on the spontaneous initiatives in the southern highlands of Tanzania (in Japanese with English summary). *Africa Kenkyu*, 85: 13–21.

Lahimer, A.A., M.A. Alghoul, K. Sopian, N. Amin, N. Asim & M.I. Fadhel 2012. Research and development aspects of pico-hydro power. *Renewable and Sustainable Energy Reviews*, 16: 5861–5878.

Maher, P., N.P.A. Smith & A.A. Williams 2003. Assessment of pico hydro as an option for off-grid electrification in Kenya. *Renewable Energy*, 28: 1357–1369.

Müller, G. & J. Senior 2009. Simplified theory of Archimedean screws. *Journal of Hydraulic Research*, 45(5): 666–669.

National Bureau of Statistics (NBS) 2011. *Tanzania National Panel Survey Report (NPS) - Wave 2, 2010–2011*. Dar es Salaam.

Okamura, T., M. Takano, I. Mizuno, K. Suzuki, H. Takimoto & H. Miyazaki 2011. Optimal design of a pico-hydroelectric power generation system with a spiral water wheel at a Japanese irrigation canal and a validation experiment. *Japanese Society of Agricultural Machinery*, 73(5): 305–312.

Shimomura, M. & M. Takano 2013. Modeling and performance analysis of Archimedes screw hydro turbine using moving particle semi-implicit method. *Journal of Computational Science and Technology*, 7(2): 338–353.

Smith, N.P.A. 1994. Key factors for the success of village hydro-electric programmes. *Renewable Energy*, 5: 1453–1460.

Tanaka, Y. 1990. *Spiral Water Wheel (Rasen Suisha)*. Private publication. (In Japanese.)

——— Accepted *December 26, 2014*

Corresponding Author’s Name and Address: Teppei OKAMURA, *Graduate School of Environmental Studies, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, JAPAN.*
E-mail: teppei.okamura [at] j.mbox.nagoya-u.ac.jp