A study of micro-hydropower plants in Nepal:

Sustainability from technical, economic and social perspectives

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Abstract— **Micro-hydro power provides electricity for homes and businesses in rural areas across Nepal. Technical, economic and social problems can all affect a micro-hydro plant's capacity to provide a consistent and reliable supply of electricity. A study of 17 sites in Nepal investigated the quality of maintenance and installation, management practices, and perspectives on micro-hydro plants. A visual assessment of sites was used to quantify the quality of maintenance and interviews were used to understand the roles and attitudes of plant operators, plant managers and consumers. The results showed successful management structures were in place at all sites and plants with trained operators tended to meet a higher standard of maintenance. However, technical issues that develop before and after a turbine's commissioning can threaten the technical and economic sustainability of plants.**

Keywords—micro-hydro; Nepal; maintenance; technical, economic; social; sustainability

I. Introduction

In Nepal, low levels of electricity production and slow expansion of the national power grid mean many people in rural areas rely on local generation. There are more than 3,300 micro-hydropower plants (MHPs) in Nepal [1], manufactured and installed by local small- and medium-size enterprises across the country. Following installation, the operation and management of these plants becomes the responsibility of members of the local community. Poor technical and economic operation of plants can limit their effectiveness in providing developmental benefits to rural communities.

Previous research has demonstrated the variability in performance and maintenance of MHPs in Nepal. Khadka and Maskey showed that the overall efficiency delivered by MHPs is very variable with 15 sites achieving between 45% and 75% at rated flow [2]. Through a survey of plant operators, Barr demonstrated that the quality of maintenance delivered by plant operators is often related to the economic benefit that electricity brings to the whole community [3].

In this study, visual evaluation was used to quantify the quality of maintenance and understand which sub-systems can limit performance and reliability. Interviews with operators, plant managers and consumers were used to understand the technical, economic and social operation of MHPs. This paper offers a summary of the outcomes of these methods. From a technical perspective, issues which threaten the performance and reliability of MHPs have been identified. From an economic and social perspective, the operation of MHPs and their impact on local communities have been documented.

II. Methodology

A. *Site selection*

A total of 17 sites were visited in the Western Development Region of Nepal. 15 of the sites were in Baglung district and 2 sites in the neighbouring district of Gulmi. All the sites visited had Crossflow turbines; the topography of these districts is more appropriate for this turbine type. There are several characteristics associated with the sites selected which should be considered when analysing the results. Baglung is well known for its density of micro-hydro sites which may lead to a better quality of installation than in areas with fewer MHPs. In addition, most villages in Baglung district are relatively accessible; there is reasonable road coverage across the district and Butwal (Nepal's "hub" for micro-hydro power) is less than a day's travel from Baglung. Compared to much of Nepal, this represents a good level of accessibility. The focus of this study was on Crossflow turbines, though it should be noted that Pelton turbines are also common in Nepal.

B. *Visual site evaluations*

At each site, a visual evaluation was carried out at the following sub-systems: intake and weir; desilting bay; channel; forebay tank; penstock; powerhouse; internal pipework and

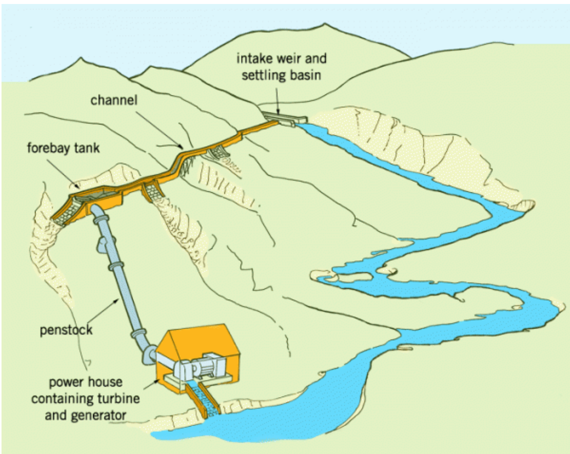

Fig. 1. Schematic of a micro-hydropower plant [4]

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valves; turbine; control panel, cabling and ballast load; and the generator. Fig. 1 shows a number of these subsystems[1]. The evaluation consisted of a qualitative inspection of each sub-system and a quantitative assessment of the quality of maintenance.

The purpose of the qualitative inspection was to understand the standard of the manufactured components and the civil installation. The observations from inspection were recorded on site and as many photos as possible were taken. These observations were aided by additional insight from conversations with plant operators and managers. In the quantitative assessment, a score for the quality of maintenance was assigned by the first author to each sub-system. For each sub-system, a specific marking scheme was used. The marking scheme was developed based on guidelines in available literature [3][5][6]. An example for the channel sub-system is given in Table 1.

There were several limitations to this method. Most critically, the assessment of maintenance only gave an indication of the quality at that moment in time. There were also problems that negatively affected the maintenance score that may have occurred due to reasons beyond the operator's control, e.g. a recent landslide causing damage. Neither did the assessment consider that the difficulty in maintaining a particular sub-system varies from one site to the next, e.g. a long canal is more difficult to maintain than a short one.

C. Interview

At each plant, interviews were conducted with a plant operator, management representative and consumer. A total of 50 interviews[2] were conducted in Nepali (by the sixth author, a community development officer) and subsequently translated into English. Where possible interviews were conducted in

TABLE I. MARKING SCHEME FOR A CHANNEL

Channel	***Very well maintained. Good evidence of regular preventative maintenance.*** Channel is clean, free from erosion with no obvious cracks visible. Obvious effort to minimise entry of debris into channel e.g. banks around channel are swept and overhanging vegetation cut back.	5
	Evidence of effort to maintain the subsystem but without following a schedule closely. Some dirt, debris and a small amount erosion is visible. Cracks may be present, but they are small and any obvious leaking is minor. Some effort to minimise entry of debris into channel.	3
	Poorly maintained. Preventative maintenance is rare. Channel is heavily contaminated with obvious signs of erosion. Cracks are significant and/or leakage is obvious. No obvious effort to minimise entry of debris into channel.	1

isolation, however due to cultural conventions, this was not always possible. Interviewees were made aware that it was an independent study for research and it would have no financial impact on the individual nor the plant. The interview with the plant operator was used to understand the maintenance practices; the questions were predominantly closed to generate quantitative data. The interview with the management representative was used to understand how the MHP plant is managed. Areas of interest included how electricity tariffs are collected, how tariffs vary, what productive end uses are present and how management respond when there is a problem. The interview with the consumer explored what they pay, what they use the electricity for and their attitudes towards the MHP plant. The interviews with the management representative and

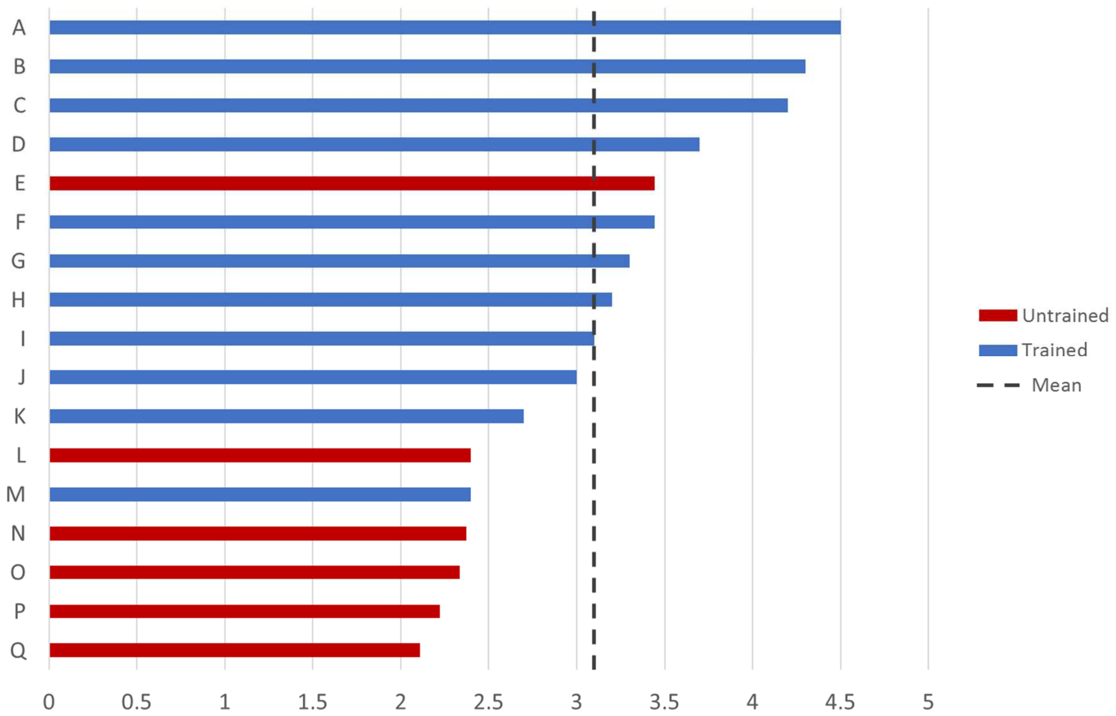

Fig. 2. Mean maintenance score by site

1 Fig. 1 refers to a settling basin which is a synonym for a desilting bay. Internal pipework and valves, control panel, cabling and ballast load are all located inside the powerhouse.

2 17 interviews were conducted with plant operators and consumers. 16 interviews were conducted with plant managers as were 2 sites with the same manager.

consumer were semi-structured allowing the interviewees to give personal insight and additional detail where necessary.

There were several limitations of the methodologies used during interviews. In many cases, the management representative or operator suggested the consumer who should be interviewed which may have resulted in bias. It was difficult to conduct interviews in private, often managers were present during the interviews of operators and consumers.

III. Results and Discussion

A. *Results from maintenance assessment, qualitative assessment and operator interviews*

The assessments of maintenance demonstrated that there was a large variability in the quality of maintenance across the sites. Fig. 2 shows the mean of maintenance scores by site. The range was 2.4 and the mean was 3.1. The better (e.g. greater than 4) and worse sites (e.g. less than 2.5) tended to have consistent good or bad maintenance respectively across all sub-systems. The sites with scores close to the median tended to have more variation in the maintenance quality of individual sub-systems.

Fig. 3 shows the mean maintenance scores for each of the sub-systems. The 3 worst performing sub-systems were the canal, forebay tank and the turbine. It was observed that canals were often cracked with vegetation overhanging or growing from the walls. Many forebay tanks had dirty trash racks and debris in the bottom of the tank. Turbines scored low due to leakage from the casing and evidence of over-greasing. Responses in interviews supported these observations, more than half of operators said that they cleaned the trash rack less than once a day whilst 11 of the 17 operators said that they greased bearings more than once a month. Both responses indicate that plant operators were performing these tasks at incorrect intervals for a typical micro-hydro scheme [5].

Of the 17 sites visited, 11 sites had trained operators whilst 6 had untrained operators. Plant operator training is a 22-day course arranged and delivered by the Nepal Micro-Hydro Development Association (NMHDA) which covers maintenance of the mechanical, civil and electrical components [1]. Interviews with untrained operators revealed that at 5 of these sites, the original operator had moved abroad for work.

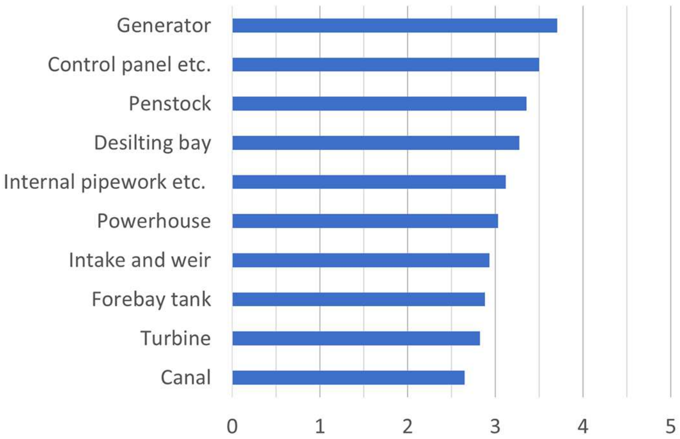

Fig. 3. Mean maintenance score by sun-system

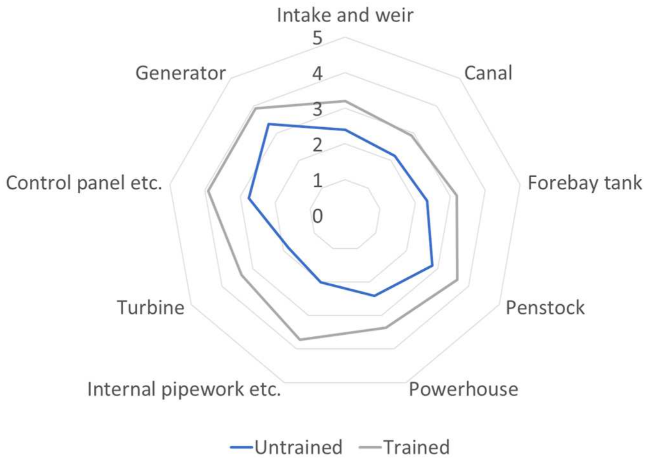

Fig. 4. Mean maintenance score by sub-systems for trained and untrained operators

Fig. 4 shows a radar graph which compares the average maintenance score for each sub-system for trained and untrained operators. The mean averages across all sub-systems were 3.5 for trained operators and 2.5 for untrained operators. The results for the desilting bay have been omitted as only 1 of the sites with an untrained operator had a desilting bay. Fig. 2 shows that 5 of the 6 worse sites had untrained operators.

The 3 sub-systems with greatest difference between trained and untrained operators were all located inside the powerhouse. On these sub-systems, by failing to complete daily maintenance tasks such as cleaning or addressing persistent issues such as leaking, a long-term lack of maintenance becomes more obvious. In general, these results are encouraging for the organisations delivering operator training in Nepal. This study demonstrates that training is effective in delivering a higher quality of maintenance.

As well as the variability in maintenance quality, a large variation in construction quality was also witnessed. Often located on steep banks, many canals were impressive constructions. In several locations, caves had been hollowed to allow a canal to pass through. The construction of desilting bays and forebay tanks was often poor and ineffective in removing silt, see Fig. 5. It was often seen that water entered bays too quickly or tended to flow along one wall. The shape of a desilting bay is critical to reducing flow velocity and allowing silt to settle. When there is high silt content in water passing through the turbine, there is more damage resulting in a requirement to replaces parts more frequently.

Fig. 5. Ineffective shape of desilting bay

Fig. 6. Leakage from turbine casing

Fig. 7. Over-greasing of turbine bearings

The construction of turbines was generally satisfactory, however, leakage from internal pipework and turbine casings was common, (see Fig. 6). The loss of pressure associated with leakage affects performance and for smaller systems could significantly reduce the available power. It was also seen that many transmission belts were running with large vibrations. During the interviews, 7 plant operators indicated that turbine bearings had broken in the previous year. Operators seemed to be prepared for this; interviews revealed that turbine bearings were the most commonly kept spare part. Although belt vibration and over-greasing were observed (see Fig. 7) other factors contributing to bearing failure such as belt wear and misalignment in shafts could not be assessed without turbine disassembly. Both leakage and bearing failure require further investigation to understand whether they are design, manufacture, installation or maintenance issues.

B. Results from interviews with plant managers and consumers

Interviews with plant managers demonstrated that all the sites in the study had well structured methods for payment collection. It was found that all the sites were using energy meters to prepare bills for customers and within each month, there is a period in which consumers can pay before they are fined. Consumers demonstrated a good awareness of the fines and responses of several plant managers suggested that payment of fines was rare. It was not clear whether this was due to timely payment by consumers or a lack of enforcement. Only 3 respondents commented that their supply was low, the remaining consumers stated that their supply was consistent and sufficient. All the consumers acknowledged that the presence of an MHP had made their lives easier and identified a range of financial, social and health benefits. When asked whether they would prefer grid electricity, the responses were inconclusive. Around half of respondents said that they would prefer grid electricity but several others felt that if load shedding continued to affect the grid, they would prefer to be connected to an MHP. Several respondents identified the hard work of the community during construction and preferred that MHPs are local as “if any problem arises, an operator can be called immediately”.

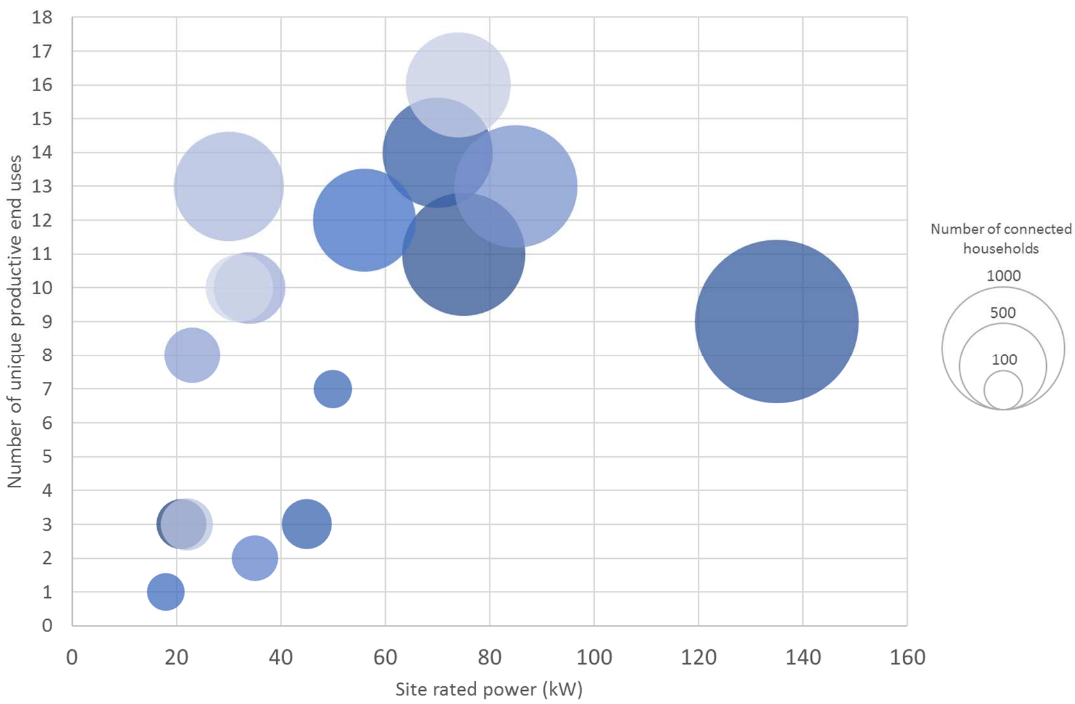

Fig. 8. Rated power against unique productive end uses and connected households

TABLE II. SOCIAL END USES

End use	Frequency
School	12
Hospital/health clinic	9
Local government office	8
Community centre	7
Post office	6
Telecom tower	3
Radio tower	2
Movie hall	1

Responses from plant managers and consumers indicated that MHPs are well established in their communities providing electricity for 25 unique productive end uses and 9 different types of domestic load and. Productive end uses connected to MHPs can deliver a range of economic and social benefits. Local businesses such as grain mills, poultry farms and furniture makers were common. Table 2 shows a range of social end uses and the number of sites where each end use was found. These end uses demonstrate the social importance that MHPs have within their communities. Fig. 8 shows the number of unique productive end uses against the rated power where the size of the marker represents the number of connected households. The graph largely shows a positive correlation between plant size and both the connected number of households and productive end uses. This is encouraging for the sustainability of plants as a good balance between commercial and domestic electricity uses provides the best opportunity to run a plant profitably. Further investigation is required to assess the combination of domestic and commercial loads that is optimal for a plant's sustainability.

C. Discussion

At 60% of sites, managers stated regular payments provided sufficient income to pay for repairs suggesting these plants were economically sustainable. At the remaining plants, managers said that when problems occurred, they were able to collect additional money from consumers to cover repair costs.

This has allowed the MHPs to be dependable electricity sources in the communities in which they reside; more than 80% of consumers said their supply was consistent and sufficient. Consequently, consumers have access to technology in their own home and facilities in the wider community which enable improved healthcare, communications and employment opportunities. The benefits provided by the end uses listed in Table 2 demonstrate the social impact that MHPs can offer. Supplying electricity to telecom towers, health clinics and schools can improve the lives of people in the local area even if they do not have a household connection to the MHP. The interviews from this study will be analysed further to understand the socio-economic position that MHPs occupy within their local communities. Technically, the results have shown that there is generally a reasonable standard of maintenance. Greater attention is required on several sub-systems which will improve the reliability of plants and reduce maintenance costs. It is encouraging that the sites with trained operators had a better quality of maintenance than those without. It is advised that NMHDA ensures that training is delivered to new operators if the original operators leave.

The data collected in this study provides an insight into the operation of MHPs in Baglung and Gulmi district. Given Baglung's reputation as a district with a good level of development in the micro-hydro sector, the results cannot be assumed to be typical of all areas of Nepal. In areas with fewer MHPs, the reduced exposure to hydropower technologies may weaken the social, economic and technical performance of plants because of a lack of expertise. In areas further from Butwal and Kathmandu, longer travel times are likely to lead to longer downtimes when technical problems occur.

IV. Conclusion

Micro-hydropower is an effective solution for providing electricity to rural communities. This study found that all the visited MHPs were pivotal in their local community and largely successful in delivering reliable power for a range of domestic and commercial loads. In most cases, the MHPs had effective management structures to run in a financially sustainable manner. A greater understanding of the financial operation of plants is required to assess how their economic, social and technical sustainability can be maximised. From a technical perspective, the quality of maintenance was a threat to the reliability of some plants. At the sites visited, the training delivered by the NMHDA was shown to result in a higher quality of maintenance, but some areas demand greater attention. Ineffective silt removal, poor alignment and leakage were observed at many of the sites. Further work is required to establish when in a project's life each of these problems originate (e.g. during design, manufacture, installation or operation) and how they can be tackled both technically and through better processes.

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