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A Socio-Technical Survey of Micro Hydro Power Projects in District Shangla, Pakistan

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***Abstract*—** Rural electrification requires to be designed in a sustainable way to improve the quality of life of rural communities. Pakistan is facing an acute energy crisis for years now. Pakistan's energy mix mainly depends on indigenous natural gas and oil. Due to imports of oil and rapid decrease in gas reserves, there is a significant burden on the economy of Pakistan, which has forced the planners and policy makers to look for renewable energy sources. Micro Hydro Power (MHP) is an example of renewable energy which can be sustainable economically, environmentally and socially as Pakistan is rich in micro-hydro power especially the northern side. This paper analyses the outcomes from a field survey which is conducted in district Shangla, KPK Pakistan, where different agencies have implemented different MHP Projects (MHPPs). The quantitative and qualitative analyses have been used for comparing two MHPPs based on electricity tariff, community involvement, effect on the society and other factors. Quite a few issues were found due to lack of knowledge or unskilful operators in maintenance and operation in these MHPPs which are barriers to sustainable development. This research work concludes that these MHPPs requires proper management, quality work and skilful operators to have a sustainable and reliable system for the community. The MHPPs area already contributing significantly in the development of local communities.

***Keywords*—** Sustainable development, Micro hydro power plant, Renewable energy

I. INTRODUCTION

This Sustainable development is the outcome of increasing awareness of the universal links between growing environmental issues and socio-economic problems much to do with inequality and poverty and worries about a healthy upcoming life for humankind. The concept of sustainable development strongly links to the socio-economic and environmental issues [1]. The world's population comprises of 80% of developing countries but they use only 30% of total world's energy [2]. The world's population is increasing with a very high resulting in increased energy consumption. With the development in information and communication technologies, the common masses are becoming more aware of the environmental hazards as well related to energy. It is becoming more important to move towards the alternative resources of energy which minimizes these environmental hazards.

Renewable energy is recognized widely to contribute well enough to the sustainable development because of its environmentally friendly nature, lowering the health hazards; mitigating climate change. Thus, renewable energy gradually getting support from government policies, multinational corporations (MNCs), nongovernmental organizations (NGOs) and industry tracking environment, energy and other developmental growth programmes locally and globally too. Renewable energy is also getting considerable importance at commercial market, shifting the investment patterns away from state and international donors to private firms and organizations [2].

Energy is the basic requirement for the development and prosperity of a nation. In fact, nowadays, the progress of a nation could be gauged in terms of how much energy it consumes per person [3]. According to International Energy Agency (IEA), the world energy demand reached to 14050 Million Tonnes of Oil Equivalent (MTOE) in the year 2017, which was 10035 MTOE in the year 2000. The world energy demand has been increased by 2.1% in 2017 as compared to 2016, in which the world energy demand was increased by 0.9% [4].

Electrical Energy is the basic need of modern life due to advancement in technology and inventions day by day. The world electricity generation was 25570 TWh in 2017, which was increased by 3.1% as compared to previous year [4]. Pakistan electrical energy sector is a developing market. For years, the issue of balancing the supply and demand for electricity has remained an unresolved. According to the population census of Pakistan 2017, the total population of the country was 207.7 million, in which the urban population is 75.5 million or 36.4% while the rest live in rural areas.

Pakistan is listed as the 6th most populous country in the world, having the availability of 43-Watt energy per capita, which is almost 1/7th of the world average [5]. The electrical energy demand in Pakistan is increasing day by day. Pakistan's recent energy mix mainly depends on fossil fuels, which is resulting in high prices of energy and also on energy crises and imported at the cost of precious foreign reserves. The total

nominal power generation capacity of Pakistan as on 30th, June 2015 was 24,823 MW; of which 16,814 MW (67.74%) was thermal, 7,116 MW (28.67%) was hydroelectric, 787 MW (3.17%) was nuclear and 106 MW (0.43%) was wind. The installed power generating capacity of Pakistan from 2000 to 2015 [6], is given in figure 1.

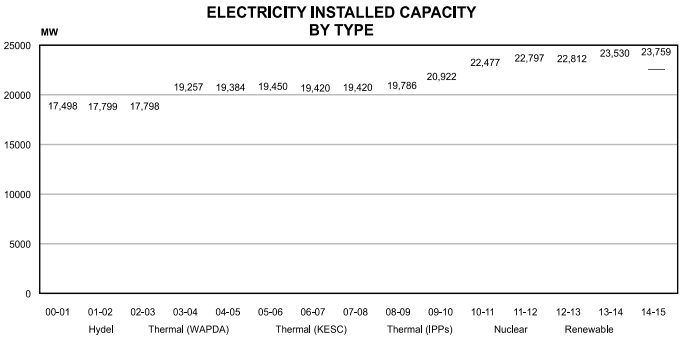


Figure 1. Total Installed Capacity of Pakistan from 2000 to 2015 (NEPRA. State of Industry Report 2015)

The rapidly growing rate of energy demand is 10% per year [5]. The future energy demand in 2030 is predicted at 110 GW as projected in figure 2. For more than a decade now, Pakistan's energy crisis is becoming chronic and the ever growing circular debt is posing major threat to economy of the country. The main causes of the present energy crisis are high cost, poor transmission and distribution system, inappropriate policies, mismanagement and the low level of energy generation compared to demand. The country's increasing population and economic activities necessitates the generation of more energy and all indigenous resources must be used before importing any hydrocarbons. The house hold and industrial level have the issues of energy conservation, overuse and misuse of energy. Other factors such as transmission line losses, pilferage losses, corruption, lack of management and lack of political consensus on the big power projects have significantly contributed to the energy crisis.

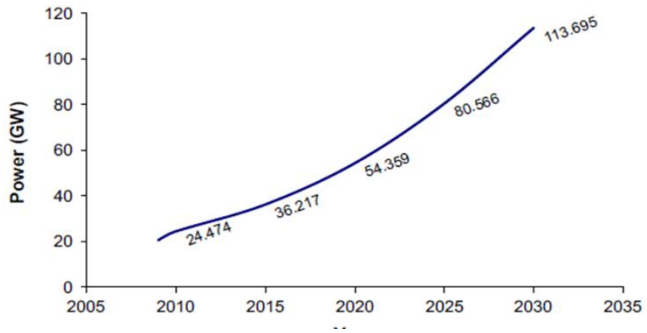
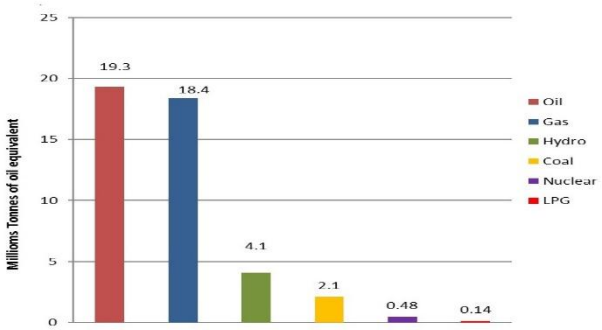


Figure 2. Future Projected Demand of Pakistan (Farooqui, 2014).

The main sources of energy in Pakistan are gas, oil, hydro, nuclear, coal and LPG [7]. The power production in the country from the primary energy resources is shown in figure 3. Due to the issues of climate alteration and environmental deprivation, the significance of renewable energy technologies has been rising. Furthermore, the international environmental agreements make it necessary for Pakistan to concentrate on renewable and clean energy options to meet its growing demand for energy [8]. The renewable energy sources include hydropower, solar energy, wind, geothermal energy etc. The energy or electricity generated from these sources is clean and environment friendly.



Pakistan Power Sector (Ministry of petroleum and natural resources Pakistan, 2008)

Hydropower is one of the most important renewable energy source providing electric energy world-wide. Small or micro scale hydro mostly "run-of-river", without dam or storage for water, is one of the most cost-effective and environmentally benevolent energy technologies to be considered for rural electrification in developing countries [9]. Small, micro and mini hydel projects have no internationally agreed definition. Different states have different definition as shown in table 1. In India, 2.5 to 25MW is categorized as small hydro [10] whereas European commission categorized hydel project less than 10MW as small hydro [6]. Pakistan renewable energy policy 2006, consider project below 50MW as small hydro [11]. According to world bank, 100kW-1MW is considered as mini hydel projects.

In current pressing energy demand, the low hanging fruits need to be targeted. The case become more viable when the questions of electrifying remote rural communities having low income is raised. Extension of grid is an expensive option and not feasible. Both federal and provincial governments have initiated many projects in small and mini- micro hydro domain. According to Alternative Energy Development Board (AEDB), Pakistan has the potential of 3100 MW power from micro hydro plants in which the operational power is 128 MW, 877 MW is in implementation process while almost 1500 MW is obtainable for the progress. The range of power potential from different regions in the country has shown in the table 2.

TABLE I. DIFFERENT DEFINITIONS OF MICRO HYDRO

Parameter	Description	Reference
Small Hydro	2-25 MW	India Energy Council
Small Hydro	<10 MW	European Commission
Small Hydro	<50 MW	Pakistan Renewable Energy Policy 2006
Micro Hydro	1-100kW	World Bank
Mini Hydro	100kW-1MW	World Bank

In Pakistan, a lot of projects have been implemented in the Kashmir, KP and FATA regions. Pakistan council for

renewable energy (PCRET) has implemented 290 plants in the range of 5-50 kW in KP, FATA and Kashmir accounting for 3.5MW. Similarly, Agha Khan Rural Support Program(AKRSP) has constructed 171 projects in northern Pakistan [12]. However, the country enters a new era, when KP provincial government announced construction of 356 micro hydro projects in KP [14]. 150 projects have been completed and 168 are under construction stage. Four local NGOs have been given the contracts to construct the micro hydro projects namely AKRSP, Sarhad Rural Support Program (SRSP), Fatima Welfare Foundation and Haashar.

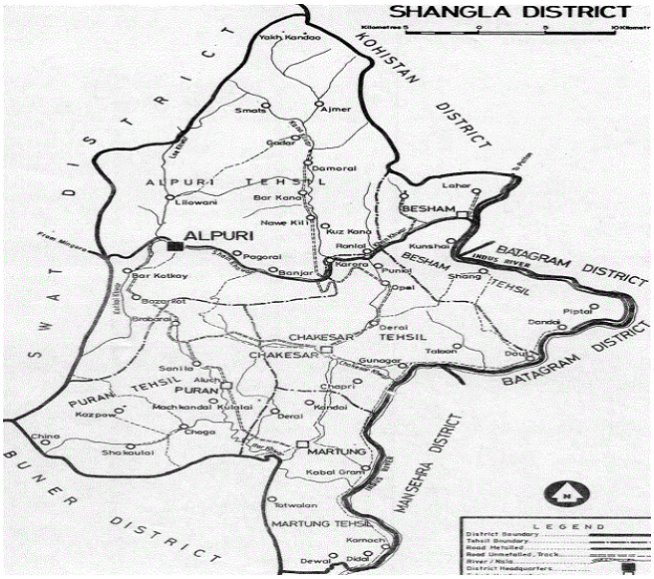
The micro/mini hydropower has the potential to provide electricity to the rural areas in the country, which include the power generation from hilly northern region and power generation through canal fall in the southern region of the country [13]. The country is blessed with hydro power potential especially the province of Khyber-Pakhtunkhwa (KP). Electrifying the rural areas can significantly change the life style and can have a good impact on the sustainable development of the country.

TABLE II. POTENTIAL RANGE FOR MICRO HYDRO POWER

Region	No. of Potential Sites	Potential Range MW	Total Potential (MW)	Remarks
Gilgit Baltistan	200	0.1 to 38	1300	Natural Falls
Khyber Pakhtunkhwa	125	0.2 to 32	750	Small / Micro based on Natural Falls / Flow
Punjab	300	0.2 to 40	560	Canals
Azad Jammu & Kashmir	40	0.2 to 40	280	Natural Falls
Sindh	150	5 to 40	120	Canal Falls
Total			**3100**	

Alpuri is a hilly place located in district Shangla, KP province of Pakistan and has coordinates of 34° 54′ 00″ N 72° 39′ 00″ E. The detailed map of Shangla district is shown in figure 4. The locality has many streams and is suitable for generation from micro-hydro. Several micro-hydro systems have been implemented in the area by different organizations. SRSP, a non-government organization, is implementing 165 community controlled MHPs having an installed capacity of 21 MW with the help of European Union [15]. Alpuri region is selected for this research due to the fact, that in recent years, several MHP's have been implemented with changing factors like funding, processes of design and mechanisms of planning and control. This research is based on investigating the social, technical and environmental impacts of micro-hydro projects implemented by government, non-governmental organizations and local community in the rural regions of KP province, Pakistan.

As mentioned earlier that Pakistan is facing a considerable energy crisis, thus there is a great need to sort out alternatives other than fossil fuels and MHPPs is one of them, for which efficient management is one of the main concerns. In order, to tackle the efficient management of MHPPs, the main objective of this work is to assess the overall performance of two MHPPs in terms of their operations, socio-economic and environmental impacts. The aim is to find out how the community is benefitted from the implementation of these MHP projects and what are the impacts of micro-hydroelectricity on the people of those regions. The research is an attempt to know the factors experienced by the locals after the installation of MHP projects such as education, health, income, economic activities, information etc.



Detailed Map of Shangla District

II. METHODOLOGY

For this research, data about the impact of these MHPP has been collected through designed questionnaire with the help of individual interviews. The site observation, designed questionnaire and the individual interviews were conducted to collect both quantitative and qualitative data in the survey, see figure 5. Field visit to Shangla district was conducted to observe and find out the households whom are benefited by this micro hydropower. The visit to the field is necessary to know the views and experiences of the local community and to identify the actual impact of MHPP in the community. Questionnaire was designed to collect the correct data from the users of micro-hydro energy in the community. The responders from the local village were obligatory to fill up the questionnaire. The questions were provided to know the views of the local community about the impact of the MHPP's in different sections of the village. Interviews were conducted from villagers, MHPP operators, maintenance staff and other related personnel to give information regarding involvement of community, its social impact, barriers and problems, details of design and technical parameters, funding, plan and policy. The interviews also required to gain the overall perspective of the interviewee for these MHPP's; their benefits, issues and future

prediction. Thus, the primary data was collected from the community households of the research area. Likewise, the secondary data was collected from different reports, publications, feasibility report, internet, journals, experts and organizations related to micro hydroelectricity. The data for the analyses has been organized and tabulated according to the objective of research studies. Simple tools for statistics were used for data analyses like tables, bar graphs etc. With the help of computer programs, like Microsoft excel, SPSS and Matlab data was analyzed. The data analysis is descriptive and analytical.

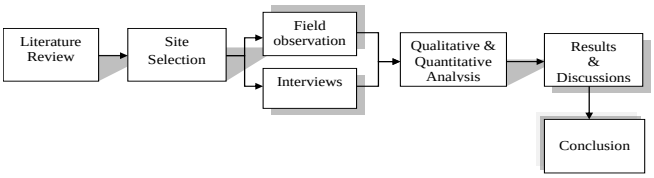


Figure 3. Research process flow chart

III. RESULTS AND DISCUSSION

The results of the survey are presented to analyze different aspects including the nature of the MHPPs, its funding and the community collaboration. The survey findings also expose the contribution of MHPPs to the sustainable development i.e. its environmental and socio-economic impacts.

A. Nature of MHP systems

The MHPPs installed in Alpuri are all run-off-the-river due to the rough location as shown in figure 6, and it is difficult to build dams for storage to gain excess of water for these systems, as the power obtained from the MHPP is determined by the head and flow rate of water to the turbine. Variations in water flow rate have a significant effect on the power produced throughout the year. The annual average flow rates were determined by the qualitative data which were provided by the local community. There was no annual flow rate data available to help the local community for the evaluation of variations in the seasonal flow rate over a long time. The MHPP's are designed with cross flow turbines with no storage system, which means that all the power generated should be either used by the community or the excess of power should be dumped. Some of the technical details are given in table 3.

TABLE III. DETAILS OF MHPP

Parameters	Lilownai MHPP	Kassbela MHPP
Total Capacity (kW)	50	25
Head (ft.)	200	25
Turbine Used	Cross Flow	Cross Flow
Manufacturer	Mukhtiar Energy, Mardan	Chiragh steel company, Mardan
Circuit breakers	Yes	No
Transformer	No	No

In Lilownai MHP system during mid-winter, the canal had minimum level of water. Although complete freezing of the canal never happens, the water-flow rate was the worst case of the year during December. The turbine was producing only 3-5 kW of maximum power under such conditions and wasmostly in overloaded situation. In summer, however, turbine was running for 21 hours out of 24 hours a day. The remaining 3-4 hours were used in cleaning of the turbine, penstock and the fore bay tank. The MHP is able to produce 10 – 20 kW power with good to great water flow. Water flow was variable but with enough thrust to keep the reservoir filled always under running condition.

Similarly, for the Kassbela MHP system, the water flow variation is high in summer as compared to winter. The sediments in the channel of water are being filtered in fore bay tank having volume of 960 ft3.

Figure 4. Lilownai MHP system

B. Funding of MHP systems

The MHP systems installed in the Alpuri region are funded by three different sources: government (PEDO), non-government organization (SRSP) and local community. The Lilownai MHP system is implemented by SRSP with some community collaboration. The MHPP was funded by SRSP and some community shares. A total of 7.78 Million PKR was assigned out of which 3.6% are community shares and the rest was SRSP fund. Technical data collected from Kassbela MHP system shows that this project was implemented in 2016 by SRSP (NGO) and funded by European Union. The land for the project was donated by local community. The total cost of the project was about 2.3 Million PKR in which 10% of amount was paid by the local community organization. The details are shown in table 4.

TABLE IV. FUNDING FOR THE MHP SYSTEM

	Lilownai MHPP	Kassbela MHPP
Funded By	SRSP	SRSP
Total Cost (PKR)	7.78 Million	2.3 Million
Community Shares	3.6%	10%

Total Capacity (kW)	50	25

C. Community collaboration

During the planning and manufacturing of both of these MHPP's, the communities collaborated and were involved with the SRSP organization. The communities mostly collaborated in the civil works; however, they are also involved in the operation and maintenance of these MHPP's. Mostly in community-based MHPP's, the locals were involved in providing fund, working on the sites and in the maintenance. Both in Kassbela and Lilownai MHP's, the locals helped during the installation stage. The members from both the community backed the SRSP in the constructing and provide their labours to help in completing the projects. The funds provided by the SRSP covered the expenses of the tools and equipment's that is; turbine set, generator, other electrical equipment's and civil materials which is required for the project.

D. Electric Power Tariffs

The Kassbela village has total of 230 household among which 100 were being electrified by this power house. Average household demand is about 20 to 25 units and has meter based billing system. Schools, shops and other local business were also being electrified. Monthly revenue coming from this project is about 20 thousand PKR and the monthly maintenance is about 10-15 thousand PKR. The details of the households electrified are shown in figure 7.

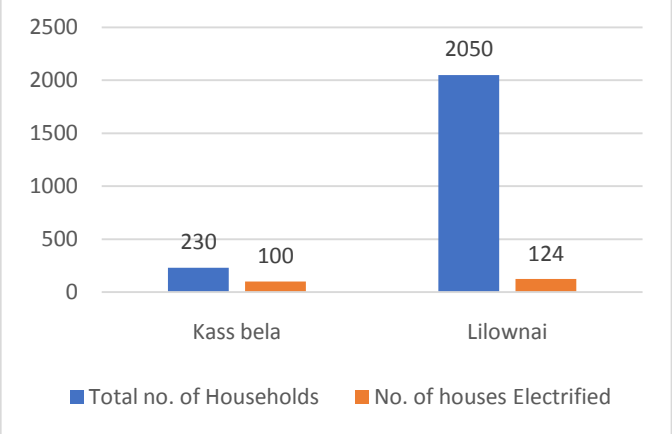


Figure 5. Number of households electrified

The tariff structure for Lilownai village MHPP is different from the Kassbela village. The Lilownai village has more than 2000 houses, out of which 200 households are near to this MHPP and number of household electrified from Lilownai MHPP is 124. Fixed tariff is allocated of 200 PKR per month for households and 300 PKR for Commercial Users. The details are shown in table 5. The bills are being paid by the community in their respective time. They pay the bill on monthly basis to a shopkeeper from where the bill is collected which is the net income of owner of MHP. If they don't pay bill in time they are fined 50 PKR per month. The monthly revenue generated is about 25 thousand PKR while the monthly maintenance cost is about 6 thousand PKR without any sudden major default. Once the bearing of generator was affected and its maintenance costs were 6800 PKR.

TABLE V. DETAILS OF ELECTRICITY TARIFF

Scheme	Kassbela	Lilownai
Electricity Tariff system	Meter Based	Fixed
Tariff Rate (PKR)	200 Average	200 for houses; 300 for commercial use
Revenue generated/Month (PKR)	20 Thousand	25 Thousand
Maintenance cost/Month (PKR)	10-15 Thousand	6 Thousand

IV. IMPACT OF MHP SYSTEMS

A. Socio-economic Impacts

The availability of electricity due to MHPP at low cost in Lilownai village has increased income generation from different sources likeshops, tailoring, hair dressers and carpenter and allows the locals to make savings on expenditures on candles, kerosene and batteries. So, the income enhances as well as the savings of the locals, see figure 8. The possibility to use appliances like freezers has improved the food and diet of the locals and decreased the malnutrition and hunger [16]. Furthermore, the load of work has decreased on women and children as they save their time by spending less time on household works i.e. collection of woods. In general, the safety of the village has increased by the lightning in streets during night time. Moreover, the education and health of the children has improved as they have more productive time to study at night and utilize the evening time by doing healthy activities. Similarly, elders can visit mosques during night time and recite holy books anytime. Lights were now available which promotes studying and reading. The availability of electricity has made it possible for the villagers to use smart phone which can also be considered an educational tool along with its other features. The villagers from the Kassbela village were very pleased with the contribution of MHPP's in their livelihood transformation. The Lilownai MHPP has a great impact on the social communication inside the community as they can arrange meetings conveniently at night and get entertained from electrical appliances i.e. Television and radio. By using these appliances, the telecommunication benefits have been enhanced, the locals are now more aware of the country and world's news which give them more information [17].

On the other hand, almost 40% locals from Kassbela village has reported that they have less communication with neighbours because of MHPP electricity as they use televisions for entertainment purposes. The decreased internal air pollution and use of woods has also positive impact on the community locals due to the implementation of MHPP's. The enhanced electrical appliances used at education institutes and medical centres have attracted more teachers and doctors to these areas which improves the education and health facilities.

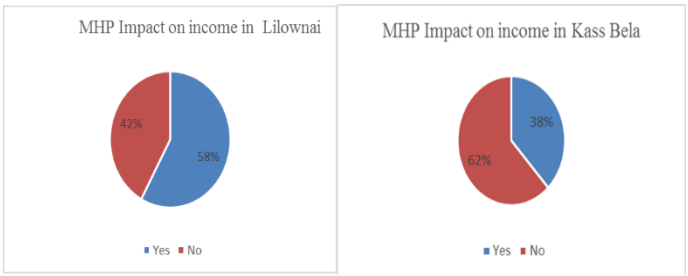


Figure 6. The percentage of respondents who reported that their income has increased after the implementation of MHPP's in lilownai (left) and Kassbela (Right)

B. Environmental Impacts

The growing population of rural areas has increased the needs for having more wood to be used for lightning and fire purposes, due to which the deforestation rate is increasing day by day. This issue requires instant and effective steps to save the forests from deforestation and keep the forests to optimum level [18]. The MHP projects implemented at Alpuri district has increased the awareness and promotion of suitable watershed management to attain sustainable usage of water resources and has minimized the deforestation.

Lilownai MHPP has a positive impact on the environmental sustainability of the local villagers, as cutting wood for heating and lighting doesn't only affect the environment but also affects the health. Fire produces hazardous smoke. Availability of MHPP has helped in decreasing the use of flammables for light source.

The lighting and cooking has a negative impact on the health as well as on the environment of the region because of burning of kerosene oil, usages of lantern, wood and coal for heating, before MHPP in Kassbela village. But all these have been somehow controlled by the start of this MHPP project. Furthermore, due to controlled wood cutting the forests helps in the protection of the environment. The reduction in the use of kerosene oil and hazardous smoke due to the MHPP helps in the combat with the climate change and increase safety around the community.

The MHP projects installed are run off river which means that there is no storage for water. The water should be directed straight to hydro turbine or the water is lost. The inflow of the water to be utilized depends on the capacity of the MHPP. The regulation of water level is served by the civil works at the intake side of the MHPP. Therefore, the run of river configuration has not same kind of effect on local environment as of large hydro power which has dams or storage for water. The variations in the water flow complicates the power generation from MHPP throughout the year.

C. Technical Issues

The Lilownai project has faced certain technical challenges during the period. In winter the site becomes overloaded about 6-8 kW due to extra load. During the last 6 months, the failure of turbine was reported 3 times; but the operator of the MHP project, Raham Khan has enough experience in MHPP construction and operation, so the issues and faults has been solved by him but each time it took 2-3 days. The generator failure has been reported only once. The transmission lines are sometimes touched by trucks which results in short circuiting. In winters, there are also issues of short circuits due to the snowfall and that are solved with the help of the local community. The turbine need frequent maintenance; the minor issues are solved by the operator however the parts and heavy machines of the turbines are not available in the area; they bring it from Mardan/Gujarghar or take the machine to that area for mending. There is also leakage in the penstock and turbine.

The Kassbela MHP project is located at a very safe place, flood resistant and have no issue of land sliding. The maintenance of the power house is under local community having less knowledge of technical studies. Therefore, if there is some major issue at the power house they contact other personnel to solve the issue. Water flow variation is high in summer as compared to winter. There were no issues regarding pipe blocking have been reported. The overloading of the turbine has been observed in summer which results in the turbine failure while in winters, short circuit issues have been observed mostly. The ratio of generator failure is ¼ per month. No power thefts have been reported yet.

CONCUSLION

The MHPP's installed in district Shangla not only electrified the villages but also developed their social and economic position. Micro hydro power systems are supposed to be a sustainable source for the economic and social growth of isolated communities. Therefore, the micro hydro power systems sustainability is very vital aspect for the alleviation of poverty. From this survey, qualitative and quantitative analyses, it is concluded that the installation of the MHPP has a significantly positive impact on both communities. The young generation who are studying in other cities are happy to return to their homes, as their homes are electrified enough to continue their studies at their own homes. In both Lilownai and Kassbela village, the locals and respondent's incomes have been increased due to the installation of these MHP systems. Most of the locals who told that their incomes have increased significantly as they now make handicrafts in the evening.

Similarly, the local tailors reported that their incomes have increased as they get electricity from the MHPPs which gave them more time to do their job. In the Kassbela MHPP, the low technical knowledge of the operator makes it difficult to have a reliable and sustainable system. There should be high level of training for the operators, to have a comprehensive idea of the MHP systems so that they can solve the issues by themselves. By high level of training, the community locals or operators could mitigate the delays in the maintenance and will not require other technical personnel from other places.

Another problem is the variations in water flow which is based on data analyses of water flow for one season. The data collected is not feasible to capture the water flow throughout the whole year which is not that accurate. In both MHP sites the water flow in winter seasons is low which results in the less electric power generation from these MHPPs. A good structure of hydrology could be achieved by using a better system to

estimate the water flow; its maximum level, average flow and minimum level, for the whole year.

Further studies and research is necessary to examine the successful key factors of establishing the MHPPs for the rural areas. The key findings from the studies could be used for the policies, planning and designing of sustainable MHPP's in the rural areas.

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