Performance Evaluation and Analysis of Micro Hydro Power Plants Installed in Chitral

By

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NUST-2013-61505-MCES-64113-F

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Supervised by

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H-12, Islamabad, Pakistan

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List of Abbreviations

MHP	Micro Hydro Power Plant
SHYDO	Sarhad Hydel Development Organization
AKRSP	Agha Khan Rural Support Program
SRSP	Sarhad Rural Support Program
MC	Management Committee
SHP	Small Hydro Power Plant
WAPDA	Water and Power Development Authority
PEDO	Pakhtunkhwa Energy Development Organization

List of Publications

1. M. Ayub, P. Akhter "Efficiency Analysis of Locally Manufactured Cross Flow Hydro Turbines. A Case study of District Chitral Pakistan" under review in Journal of "Energy for Sustainable Development"

2. M. Ayub , P. Akhter and K.V. Sharp "Efficiency Analysis and Evaluation of Micro Hydro Power Plants Installed in Chitral" 6th Annual Pacific Northwest Water Research Symposium held in Oregon State University, USA on 18-19 April 2016

3. M. Ayub and P. Akhter "The financial Mechanism of Micro Hydro Power Plants in Chitral and its impact on Sustainability of MHPs" International Conference & Exhibition on Renewable Energy Technologies held in Islamabad on 18-20 October,2016

Abstract:

Pakistan is off course blessed with a huge potential of renewable energy, but so far it remains underutilized. The result is the huge shortfall of electricity that we are facing currently. The single renewable energy source that Pakistan possesses in abundance is the Hydro Power which is more environmentally friendly and cheapest source. This abundant, cheap and environment friendly source that we have still remains underutilized. The best way to harness this huge source is the installation of small hydro plants rather than building huge dams that require huge investments, more construction time and are not environmentally friendly. Hundreds of these plants are installed in Pakistan in areas like Gilgit Baltistan, Chitral and the northern areas which have the maximum number of feasible sites.

These micro hydro plants are the only source of electricity for isolated areas which are far away from the national supply of electricity. Supplying electricity to these areas from the national grid is not possible due to lack of physical infrastructure, financial constraints and geographically scattered population. These areas have huge potential of producing electricity from the natural potential in the water coming down to these valleys from high peaks. Micro Hydel Power Plants or MHPs have become popular in such areas due to their independence from the national grid and affordable energy costs. The major objective of installing a micro hydro plant is to fully utilize the available natural resource in most appropriate manner. A number of these micro hydel plants are installed across the northern areas of Pakistan. These micro hydro plants are providing electricity to areas where supplying electricity from national grid was once considered impossible.

Although a number of micro hydel power plants are installed across but there is lack of information about their performance. Once build they are handed over to the community to manage. There is a need to know about these plants that how are they performing after installation. Either they are meeting the requirement or not. What were the problems faced during and after their installation?

What is their socio economic impact on the region where they are installed?

The basic theme of this research is to find answers to all these questions by evaluating the performance of already installed micro hydel power plants in Chitral.

Chapter 1

Introduction

Pakistan at present is facing a serious and flagrant power crisis. A large section of population in Rural Areas is deprived of the energy supply whereas the population residing in Urban Localities has to face daily load shedding about 8 to 14 hours. The situation is worst in rural areas where the residents face load shedding of 12 to 18 hours [1]. Standard of living and quality of life are two factors to measure a country's economic development and unfortunately energy has a direct impact on them [2]. With the existing power generation capacity it is impossible for Pakistan to provide electricity to the rural inhabitants as our supply of energy is not enough to meet the current demand. Moreover, a large portion of rural areas are either too geographically scattered or remote or connecting them to the national grid is not economical[3]. So Pakistan like, like other developing countries of the region, is trying to adopt Distributed Generation for its rural areas. Distributed Generation is a mechanism through which electricity is generated at the point of consumption from any available energy source and this generated energy is distributed locally [4].The most common sources of energy for Distributed Generation are Small Hydro Power, Solar and wind. .Fortunately Pakistan has a great potential for all these renewable resources especially Hydro Power.[5]

1.1 Hydro Power in Pakistan

According to estimates Pakistan is has a potential of generating approximately 41722 MW from Hydro Power only. Most of this potential lies in the water abundant KPK province, the Northern areas and Azad Jammu and Kashmir [3] . However, a large portion of this potential is still untapped and needs to be harnessed. The total generating capacity of the hydropower stations installed in the country is about 6595 MW, out of which 3767 MW is in NWFP, 1698 MW in Punjab, 1036 MW in AJK and 93 MW in the

Northern Areas (Fig 2.1) [6]. A summary of the hydel projects in various stages of implementation in different provinces of Pakistan is shown in Table 2.1

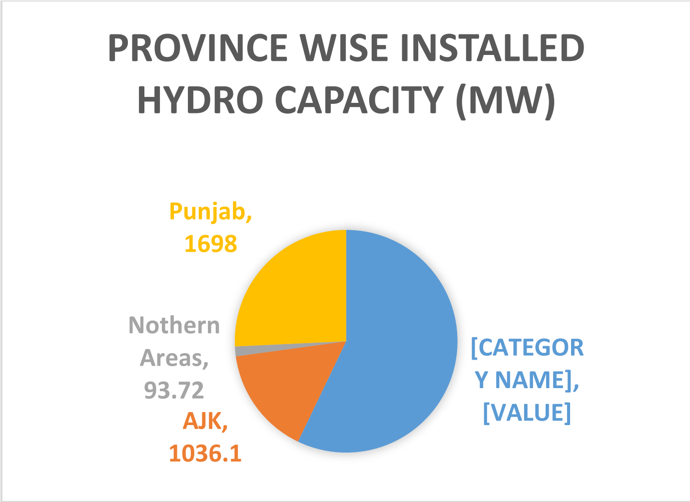

Figure 3.1 Province wise installed Hydro Capacity

Table 1.1 Hydel Projects in Various stages of Implementation [6]

Province	Project in Operation MW	Public Sector Projects MW	Private Sectors Projects MW	Projects with Feasibility study		Raw Sites	
				Above 50Mw	Below 50MW	Above 50MW	Below 50MW
KPK	3767.2	635	84	58	143	13584	426
Punjab	1698	96	nil	3720	32.17	nil	349.65
AJK	1036.1	973.8	828.7	420	48.2	1152	177
Northern Areas	93.732	18	nil	505	71.5	10905	814
Sindh	nil	nil	nil	nil	49.5	80	48.55
Baluchistan	nil	nil	nil	nil	0.5	nil	nil
Total	6595.032	1722.8	912.7	4703	344.87	25721	1815.2

1.1.1 Small Hydro Power Plants (SHPs) in Pakistan

The term Small Hydro is referred to plants up to 50 MW of capacity limit and within the range of small hydro power, mini hydro refers to plants under 1MW, micro hydro to below 250KW and Pico hydro to plants below 5KW [7]. Due to prevailing power shortage in Pakistan and the inability of the authorities to install new power plants, the attention is being given to, Mini and Micro hydro generation in different parts of the country. The federal and provincial governments have established several institutions for this purpose such as

* Alternative Energy Development Board (AEDB)

* Pakistan Council for Renewable Technologies (PCRET)

* Energy and Power Department

* Sarhad Hydro Development Organization (SHYDO)

* Northern Areas Public Works Department

* Various NGOs and Private Sector

The Small Hydro Power Plants are economical in installation as well as maintenance. Local distribution and decentralized nature help reduce the distribution losses from SHPS[8]. The electricity from these SHPs can be utilized in domestic as well as commercial purposes for operation of small to medium size industries. Community has an active participation in initiation, installation and operation of SHPs. Table 2.2 below shows SHP resources in Pakistan by province. SHP in Pakistan has mostly been harnessed in the northern part of the country as the water resources ae scarce in Sindh and Baluchistan due to their dry climate [9].

Table 1.2 SHPs in Pakistan (up to 50 MW)[10]

Province	Operational		In Progress	
	Number of Plants	Installed Capacity MW	Number of Plants	Capacity MW
Gilgit Baltistan	78	44.275	15	49.83
KPK	8	125.8	7	115.68
AJK	8	38.8	11	25.47
Punjab	5	64	6	30.31
Total	99	272.875	37	221.29

Apart from these installed SHPs the northern parts of the Pakistan are blessed with water abundance and naturally feasible sites for the installation of more Small Hydro Power plants to meet the electricity needs of the rural population living in these areas. A province wise potential of SHPs is given in Table 2.3

Table 1.3 Region Wise Potential of SHPs in Pakistan [6]

Region	Capacity MW	Completed Feasibility Study		Raw Sites Identified	
		Number of Sites	Capacity MW	Number of Sites	Capacity MW
KPK and FATA	564	13	143.0	78	426.41
Gilgit Baltistan	764	7	71.5	136	814.15
Azad Jammu and Kashmir	337	9	78.10	24	177.0
Sindh	191	5	69.05	3	48.55
Punjab	409	6	131.28	306	349.0
Total Potential	2665	40	492.93	547	1815.11

1.1.2 Micro Hydro Power Plants in Pakistan

According to the Alternative Energy Development Board (AEDB) the province of KPK has potential of generating 300MW from Micro Hydro Power Plants only [10]. A number of these MHPs are already installed across the province by different private and public organizations. The summary of Installed MHPs is given in Table 2.4.

Table 1.4 Summary of Installed MHPs (up to 150 kW) [6]

Region	Number of Installed Plants	Installed Capacity kW	Households being Served
KPK and FATA	470	6790.5	59437
Gilgit Baltistan	22	401.5	4010
Baluchistan	3	80	800
Azad Jammu and Kashmir	43	592	3915
Total	538	7864	68162

The government of Khyber Pakhtunkhwa is taking keen interest in tapping the MHP potential of the province by installing MHPs across the province. The plan is to install 250 MHPs across the province in the coming years.

Post project evaluation is an integral part of a planning process. It helps in finding out that what went well and what went bad during the project. In majority of the developing countries including Pakistan no proper attention is paid to the post project evaluation [11]. Although a number of micro hydel power plants have been installed across Pakistan but their performance has not been evaluated yet. No one knows that what are the lessons to be learned for future installments of such plants and how mistakes can be met and difficulties can be avoided. There is a need to know about these plants that how are they performing after installation. A detailed research on the performance evaluation of already installed plants and their evaluation can serve as a future reference either they are meeting the requirement or not. What were the problems faced during and after their installation? What is their socio economic impact on the region where they are installed?

By this research the organizations and government can be benefited and it will help in enhancing the performance of Micro Hydro Plants that are to be installed in the near future. The basic aim of this research study was to find answers to all these questions by evaluating the performance of already installed Micro Hydro Power Plants in Chitral. The reason for selecting Chitral for this study was its huge capacity for these MHPs and also it had the maximum number of installed MHPs in the region.

1.2 Study Area (Chitral)

1.2.1 Population

According to the 1998 census, The population of Chitral is 318,689 [12]. Since the 1981 census the population has increased at an annual rate of 2.5%.Increasing at this rate the population is estimated at being 462,000 at the end of 2016. 54. Variety of ethnic groups resides in Chitral with different languages and customs. The majority belong to the ethnic group Khow and Khowar is their language [13].

1.2.2 Geography

Chitral is the northernmost district of the Khyber Pakhtunkhwa province of Pakistan, bordering Afghanistan in the west and the Federally Administered Northern Areas of Pakistan to the east (Fig. 1). The district is divided into two sub divisions (Lower and Upper Chitral).The total area of the district is 14850 square kilometers [12]. It is bounded by the three famous mountain ranges, Hindukush on the northwest, Karakorum on the north-east and to the south is the Hindu Raj range [14]. The Lawari pass (3,118m) in the south is the only entrance to this district. It connects the district to the rest of the country. The majority of people in Chitral are marginalized through poverty, remote location and harsh weather, where even basic amenities of life are not available [15]. Overall 32% of the total population lives below poverty line. Their major source of income is from agriculture and holding livestock. Women are mainly involved in agriculture activities, while men out-migrate for seasonal labor. Only 3% of the total land is comprised of natural forest, thus the communities rely heavily on farm forestry for heating and cooking fuel purposes [12]. Supply of electricity to the geographically scattered population of these mountainous regions is very difficult and only 68% of the population currently has access to electricity and 50% of the electricity comes from micro hydro plants [16].In addition, the majority of the population is settled in off-grid areas, with no access to electricity facility. This situation is unlikely to change as extension of the national grid to these areas is cost prohibitive due to the remoteness of areas and the difficult terrain.

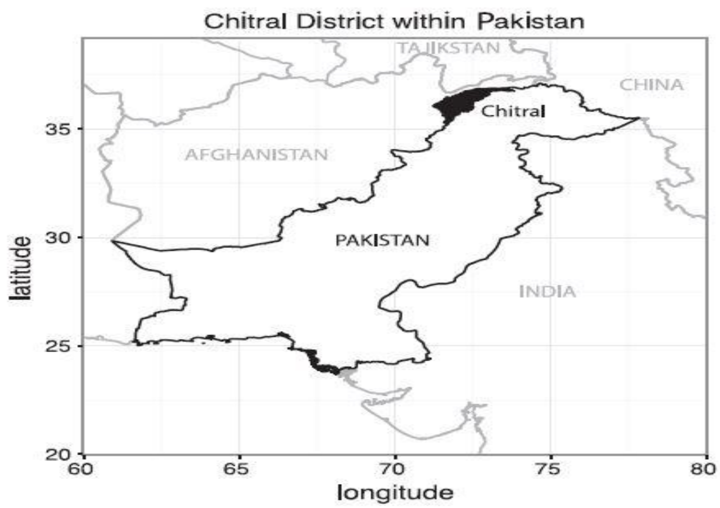

Figure 1.2 Location of District Chitral within Pakistan

1.3 Existing Power Supply in Chitral

The main source of energy for space heating and cooking purposes in Chitral is fuel wood particularly during the winter's months. About 90 % of the urban and 100% of the rural Chital is dependent on fuel wood. Other agricultural residues, non-wood materials and cow dung are also used for these purposes. The low income of people, high fuel prices and limited availability of commercial fuels are the major hurdles to shift from one energy source to another [13].The southern two valleys of Chitral (Kalash Valley and Shishi) are the main fuel wood suppliers. The transport of fuel woods from these valleys to other parts of Chitral nearly doubles its cost. Oak tree forests and fruit trees are the main source of this fuel wood. The oak forests grow between 1,200 and 1,800m above sea level and are likely to become endangered within a few years [17]. The source of fuel wood (Oak Forests) are being exploited because there is a lack of ownership because of it being a government property. This ultimately leads to the destruction of forests as regeneration is missing at lower elevations due to uncontrolled grazing.

1.3.1 Electricity Situation in Chitral

The Water and Power Development Organization (WAPDA) supplies electric power to Chitral. This is done in two ways: First, a transmission line of 33kv connects the district to the national grid and secondly WAPDA runs a Hydro Power Station of 1 MW in Chitral Town. A second contributor to electricity in Chitral is the Sarhad Hydel Development Organization (SHYDO) that operates a 2.8 MW hydro power station, at about 60 km north of main Chitral Town, at Reshun. Several NGOS have also contributed a number of micro Hydro Plants in areas of Chitral where there is no grid electricity. It is estimated that the current demand of electricity for 52,000 households of Chitral is 35 MW, whereas the existing capacity of generating electricity is only 21 MW. Thus, there is huge gap between demand and supply of energy in the area. Demand is set to increase sharply in the near future due to increase in the population (2.5%) coupled with increased industrialization in the area. Table 1.5 shows the current electricity situation and the major contributors of Chitral’s electricity.

Table 1.5 Electricity Situation in Chitral

Institution	Units Installed	Capacity (MW)	Percentage Share (%)	Total Beneficiary Households	Total Population Beneficiaries
Water and Power Development Authority (WAPDA)	Singur Power House	1	17.8	15475	108325
	National Grid	2.8			
Sarhad Hydel Development Organization (SHYDO)	Reshun Power House	4.2	28.1	9100	63700
	Sheshi Power House	1.8			
Sarhad Rural Support Program (SRSP)	MHP Plants	0.45	2.1	950	6650
Agha Khan Rural Support Program(AKRSP)	MHP Plants	10.975	50.5	7016	49117
Private	MHP Plants	0.6	2.8	1350	9450
Total		21.37 MW		33891	237242

1.4 Summary

The total hydro power potential of Pakistan has not been fully investigated, but a conservative estimation is that Pakistan has a capacity of generating 45,000MW from hydro power only. This consists of all types and size of hydro power plants, including storage based, high heat and run of river plants. The installed hydroelectric power in Pakistan is 6608MW, Out of this 5928MW is of large plants (>250), 437MW is of medium plants (>50 and <250) and remaining 253MW is of small hydro plants installed mostly in the northern parts of the country. This amount of 6608MW is only 15% of the total identified potential of Pakistan.

Within the range of small hydro power, mini hydro refers to plants under 1MW, micro hydro to below 250KW and Pico hydro to plants below 5KW. In developing countries, these plants are installed to provide electricity to remote areas where the electricity grid is not available.

Pakistan Council of Renewable energy Technology (PCRET) has implemented 290 micro hydro plants in the Federally Administered Tribal Area (FATA) and Kashmir has a total capacity of 3.5MW. The plants range from 3kw to 50kw. Similarly Aga Khan Rural Support Program (AKRSP) has constructed 171 micro hydro units in the isolated regions of northern Pakistan, which are providing electricity to 11,000 households. PCRET has set a target of installing 20MW micro hydro plants across the country to provide electricity to 100,000 houses by 2020.

The total electricity demand of Chitral is 35MW and the current generating capacity of power plants installed in Chitral is 21 MW. Out of this 21 MW, 12MW is from MHP plants installed throughout the district by various NGOs. The remaining 9MW is from hydropower plants owned by WAPDA and PEDO.

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Chapter 2

Literature Review

To diffuse decentralized rural electrification in developing countries there have been many studies which have brought out that such programs had mixed success. Although the contribution of small hydropower projects in most nations electricity needs is often very less but their importance exceeds their size. The prominent aspects of MHPs which are studied across the globe by various researchers are:

1. Technical Aspect
2. Feasibility Aspect
3. Socio-Economic Impacts
4. Barriers to MHP development

2.1 Technical Aspects of MHPs

Kendra V Sharp constructed a lab scale experiment to test the operating characteristics of impulse turbines. The effect of speed ratio on turbine efficiency were studied. The results were compared to similar tests on a Pelton turbine. At speed ratio of 0.46 the efficiency of the turbine was 80% which is good for pico-hydro turbines [1].

Hoesini et al. presented a design of MHP plant in Indonesia. The design included analysis of head, type of turbine, discharge and the potential of power generation. Simulation was done using turbine-pro software [2].

N. Baneshwo carried out a study in Nepal and classified MHPs into three categories, the water wheel, the multi-purpose power unit and the cross-flow turbine. The interconnection and various factors effecting these categories were discussed [3].

Bilal Abdullah Nasir calculated design parameters of cross flow turbines at peak efficiency. These parameters included length, speed and diameter of runner, turbine power, and number of blades the blade exit angles [4].

B. Ogaya et al. developed a series of equations to determine the cost of MHP from parameters like power and head. The equations were developed common types of turbines i-e Pelton, Francis, Kaplan for a power range below 2MW.[5]

2.2 Feasibility aspect of MHPs

Micro-hydro power continues to grow around the world, it is important to show the public how feasible micro- hydro systems actually are in a suitable site. The only requirements for micro-hydro power are water sources, turbines, generators, proper design and installation, which not only helps each individual person but also helps the world and environment as a whole.

B.A Nasir evaluated technical and economic feasibility of the repowering of one of the oldest Sicilian hydro power plant currently abandoned and disused. The reactivation of the Catarrate hydropower plant allows producing energy from renewable source contributing to the energy independence of the local community, with an energy yearly production of about 220 MW. Moreover, the author analyzed the attractiveness of SHP as a local investment [6].

Nouni et al. Discussed technical and economic feasibility of few (MHP) projects in India. The study analyzed different costs associated with MHPs including capital cost, cost of power distribution, cost of sub systems and per unit cost. The study also estimated the unit cost of electricity generation from MHPs. Further, this study also proposed suggestions for investors [7].

Another research study carried out by *S. P. Adhau* presented case studies of MHPs in India. The article discussed different turbine and generators and their performance under different flow and discharge conditions [8].

R. Khan carried out another research study in India in an attempt to investigate the sustainability aspect of MHPs in India. The study was based on data collected through interviews with different stake holders of MHP sector. Benefits and challenges were highlighted and recommendations were made to make the MHP sector a success. The results showed that the three dimensions of sustainability i-e social , economic and environmental are being realized but efforts are needed in order to make this sector completely sustainable [9].

Lea Kosnik determined the cost-effectiveness of developing small scale hydropower sites in USA. According to the author having necessary topographical features does not mean that an MHP site will prove cost effective. This results of this study showed that the average cost of installing small hydropower site is relatively high and still there are hundreds of sites in USA that are cost-effective to develop right now.[10]

2.3 Socio- Economic Impacts of MHPs

Gurung et al. carried out a study in remote villages of Sikles in Nepal to assess the impact of Micro Hydro Plant on socio economic condition. Results of the study revealed that the village electrification had brought certain changes in the rural livelihoods. The firewood consumptions was reduced and the use of traditional kerosene lamps was completely abandoned. The electric lights provided additional hours for evening work and reading thus the day was extended [11].

A study was carried in Laos by *Korkeakoski et al*. to study the impact of micro hydropower (MHP) based electrification on rural livelihoods .The study assessed the social and environmental impacts of the project. The results indicated that life became easier and there are more income generating activities going on after the installation of MHPs. Workload has also decreased. In addition, the cultural life has been enhanced and the access to knowledge and information has improved [12].

Another research work addressed the impacts of the small hydro projects on villages in India. The participation of communities in these projects was studied and the environmental friendliness of small hydro plants was investigated. The study concluded after providing a discussion on environmental benefits from these small hydro plants [13].

Angsarang reported the socio-economic impacts of MHPs in Nepal. The results of the study showed that MHPs have a positive impact on employment and income. The provision of electricity through these MHPs have helped to reduce the expenditure on alternate energy resources. The education status and health conditions of people has improved. Study hours of students have been improved after installation of these MHPs[14].

2.4 Barriers to MHP Development across the Globe

Bhutto et al. investigated the progress and challenges for small hydro power generation in Pakistan according to the overall concept of sustainability and identified the region wise potential of hydel power in Pakistan. Barriers were examined and Policy issue and institutional roles and responsibilities were discussed [15].

A case study was carried out in Bolivia and Bangladesh by *Drinkwaard et al and Razan et al.* to find out the barriers to the development of MHP projects in the country. The study comprised on interviews, site visits and conversations with communities. Data from various feasibility studies and reports was also incorporated in the study. The study suggested that Bolivian MHP sector requires a change in policy. Construction methods have to be improved and providing technical training to the community is a must for the sector to develop. The installing authorities must maintain links with the community after project completion [16] .[17]

In a two phase research project was carried out in the UK, *Bracken et al* studied the role of communities in development of MHPs. First phase was a web based survey of policy context for MHPs in the UK. The second phase involved a policy assessment in England , Northern Ireland, Scotland and Wales [18].

O Paish and *Praveen* reported that wherever a hydropower source exists, there is no more cost-effective, reliable and environment friendly sound means of providing power than a hydropower system. The author analyzed certain shortcoming which are a barrier to the development of MHPs across the globe. The major factors were the site specific nature and lack of familiarity with the technology [19] [20]

2.5 Summary

Different aspects of MHPs have been studied by researchers across the globe. All these studies have revealed that these MHP plants had mix success. In some countries like Nepal and India they are providing electricity to the dispersed populations efficiently. A large portion of India is dependent on these MHPs are they are the only source available to them. Developing countries like the UK are also focusing on MHPs as a source of distributed generation. They are a compulsory part of energy policies of developing as well as developed countries because of their economic friendly nature and less time required for installation.

Post project evaluation is an integral part of a planning process. It helps in finding out that what went well and what went bad during the project. In majority of the developing countries including Pakistan no proper attention is paid to the post project evaluation. Although a number of micro hydel power plants have been installed across Pakistan but their performance has not been evaluated yet. No one knows that what are the lessons to be learned for future installments of such plants and how mistakes can be met and difficulties can be avoided. The only available literature related to MHPs in Pakistan is the province wise potential of MHPs. The technical, economical and socio-economical aspect of MHPs in Pakistan have not been looked into.

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Chapter 3

Methodology

3.1 Data acquisition and compilation

The district selected for this study was Chitral district of KPK province. Chitral is the north most district of KPK bounded by the three famous mountain ranges namely, Hindukush, Himalayas and the Hinduraj. The reason for selecting Chitral is that it was the pioneer district to Install MHPs and secondly it has the maximum number of installed MHPs in the region. Apart from the installed MHPs Chitral is also the leading district in terms of ongoing MHP projects.

The data about the MHPs was collected in two ways

1. Meetings with the Installing Organizations
2. Visiting the project sites

The details that were collected about these MHP plants in Chitral are:

I. Year of initiation
II. Capacity of the MHP
III. Total project cost
IV. Community contribution in total cost
V. Number of beneficiary households
VI. Current status of the MHP project

After collecting all the data a Microsoft excel based database was generated containing all the above mentioned details about the MHPs plus added information about other costs like the labor cost of each project and the maintenance fund available for each project

3.2 Software Tools used

The main software used during this study are:

3.2.1 ARCGIS

ARCGIS is a licensed tool used for various GIS applications throughout the world. . It is a basic tool for map viewing and printing.it has a number of integrated applications like ARCMAP, ARC Catalog and ARCTOOLBOX. .In this study ARCGIS was used for the mapping of MHPs located across Chitral. A physical map of the MHPs was generated. The generated map include all the details about MHP plants discussed in section 3.1. Fig 3.1 shows the map created using ARCGIS.

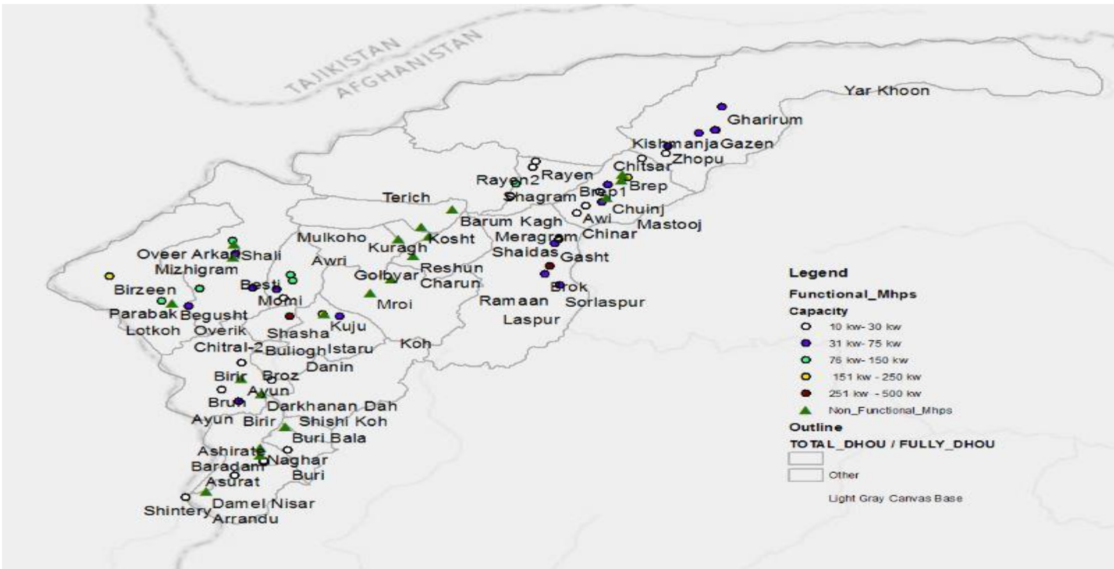

Figure 3.1 ARCGIS mapping of MHPs

The maps created using ARCGIS are in ESRI format which is only readable in ARCGIS software which is not available to all. So another Mapping software was used so that everyone can access the generated MHP map.

3.2.2 Google Maps

Google map is an easy to use desktop based mapping tool developed by Google. It as a user friendly and easily accessible tool. The map generated using Google Map is shown in figure 3.2.

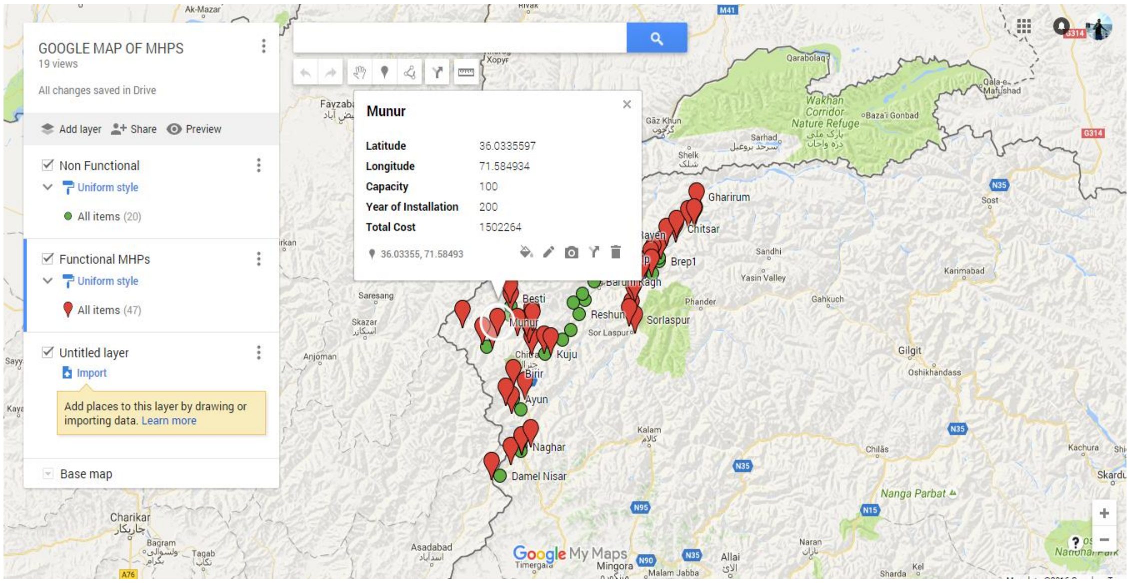

Figure 3.2 Google Mapping of MHPs

3.2.3 RET Screen

A decision support system tool developed to help decision makers and planners in developing renewable energy projects is the RET Screen Clean Energy Project Analysis Software. It was developed by the contributions of experts from academia and industry. It is used worldwide for evaluation of energy production and savings from various types of renewable energy technologies [1]. It can also evaluate emission reduction and financial viability of energy projects. Hydrology and climate database can also be incorporated in this software [2]. This software is available online with a detailed user manual and a case study based training course. It is available in 26 different languages as well. The RET Screen Small Hydro Project Model with the software can be used world-wide to easily evaluate central-grid, isolated-grid and off-grid hydro projects, ranging in size from multi-turbine large, small and mini hydro installations to single-turbine micro hydro systems.

To-date, stakeholders have saved an estimated $2 Billion worldwide through the use of the RET Screen software, databases and related training material. More than 132,000 people in 222 countries now use RET Screen, and the number of people benefiting from this decision-support and capacity-building tool is growing at more than 900 new users every week [3].

RET Screen can of asses all types of renewable energy technologies (RETs) viability factors such as availability of energy at the project site, performance of equipment , initial costs, projects periodic costs, finance, income and saving, environmental credits etc. The meteorological data that is incorporated in the software includes the ground-based meteorological data and meteorological data derived from satellite. The hydroelectric model of RET Screen can be used worldwide. The same has been used for the financial feasibility analysis of 3 different MHPs in Chitral.

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Chapter 4

Results and Discussions

4.1 Micro Hydel Program in Chitral

The first step in the establishment of a micro hydro power project is always led by community demand with community representatives initially approaching an NGO to explore the possibility of support. The organization then initiatives a three- stage ‘dialogue process. Therein great emphasis is put on ensuring that the community takes responsibility for the project. During the 1st Dialogue, the organizations approach is explained to the community and the VO/WO/Cluster, if not already existing, is formed and a possible project is selected. In order to assess the feasibility in the 2nd Dialogue, a technical and social survey of the proposed project is conducted and potential points of conflict are discussed with the community. During the 3rd Dialogue the Terms of Partnership (ToP) about the division of responsibilities between installing organization and the community are drawn up and signed by representatives and all members of the community organization. This dialogue usually takes place in an open area with the majority of households to ensure the maximum possible participation and transparency.

According to the Terms of Partnership the responsibilities of organization are generally as follows:

- *Non-Local Materials and Labor Costs*:

NGO only provides non-local material, e.g. mechanical and electrical equipment; the provision of local materials like the wooden poles or stones for the construction of the channel and powerhouse are to be supplied by the community. NGO meets the costs of skilled labor as well as a certain share of the costs of non-skilled labor. That means that all work on the micro hydel – especially the channel, where unskilled labor is required – is conducted by the VO members. NGO pays them for their work but with wages that are lower than the standard rate for unskilled labor. The difference is the community contribution to the project. Dependent on the negotiations with the community but also due to differing donor requirements, the communities contribute in this way between 10 to 50% of the total scheme costs. In some rare cases communities even make a cash contribution.

- Limited Support During operation:

The installing NGO is not responsible for purchasing the land for the site of the project. It provides financial support only according to the agreement and will not increase or decrease it afterwards. NGO will not pay any emergency expenses (e.g. due to natural disasters) incurred during the construction of the project.

- *Right of support withdrawal*:

If the community breaks the agreement, then installing organization has the right to withdraw its support during the construction of the project.

The community has the following responsibilities:

- *Project Identification*: The community has to agree on a project on a need basis. Provision of Local Materials and Labor.
- *Provision of Project Site*: The site identified for the project (powerhouse and channel) has to be provided by the community free of costs.
- *Conflict Resolution*: The community has to solve all conflicts raised before, during or after the construction of the projects.
- *Financial Records*: The community is obliged to maintain a record of all the expenses incurred in the project.
- *Maintenance of Project*: The community has to complete the project in the estimated completion period (generally between three and six months) and ensure the maintenance of the project after the completion.
- *Formation of Committee*: In order to monitor the construction of the project according to the given design, the community has to form a committee that is accountable to the VO. In practice, however, three committees are formed, namely a Financial Committee, accountable for keeping bills and receipts during

the construction process, a Project Committee responsible for the construction process and an Electric Management Committee (EMC) responsible for all maintenance activities. The first two committees mentioned are generally dissolved after the completion of the construction.

- *Maintenance Fund*: In order to have sufficient financial liquidity in case of larger breakdowns, the community has to raise a Maintenance Fund.

If the ToP are agreed, a first share of the costs is released to the community and the implementation is i can be obtained in future.

The predominant load served by the MHP projects in remote locations is for consumptive applications water heating and space heating by using simple resistive electric heaters. Some households have electricity-operated mixers for use in the kitchen. So far as productive loads are concerned, there are one or two grain grinding mills in the area/ village. Keeping in view the duty cycle for these loads, there is very small load during the daytime. Most of these types of MHP projects are generally operated for about 14 h from 5.00 PM to 7.00 AM in the hilly regions.

4.1.1 MHP Development in Chitral

There are many hilly areas in the world where the grid will probably never reach. Chitral district of no Chitral. The aim was to provide low-cost electricity to remote villages of the area. Since then almost 165 MHP plants have been installed in the district. The installed plants are of different capacity ranges depending on the need of the village they are installed. The capacity of these MHPs ranges from 10 kW to 250 kW. Fig shows the total number of plants of different capacity ranges.

Fig 4.1 shows the year of installation of MHPs in Chitral. It is evident from the figure that with the pass

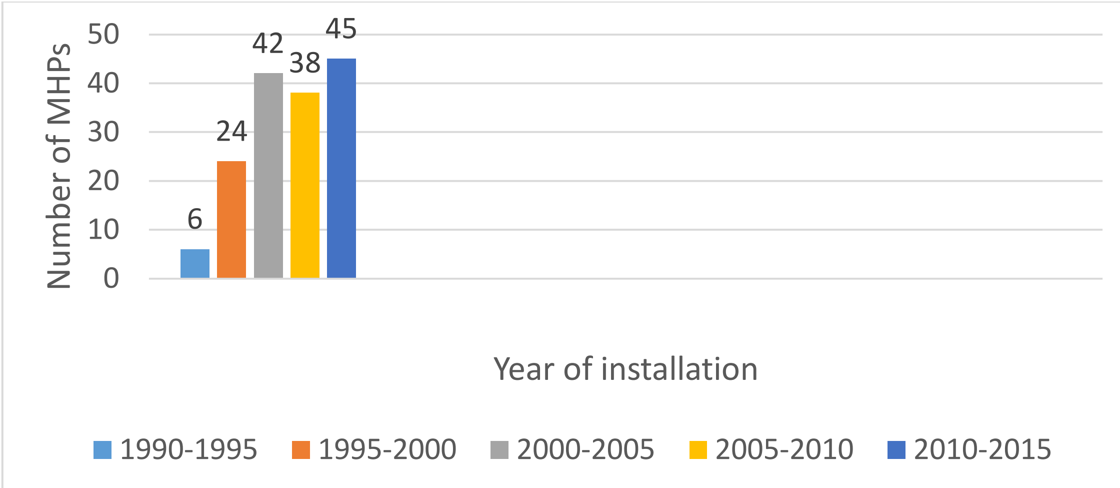

Figure 4.1 Year of Installation of MHPs

Fig 4.1.1 shows the capacity ranges of MHPs installed across the Chitral. Maximum number of MHPs a

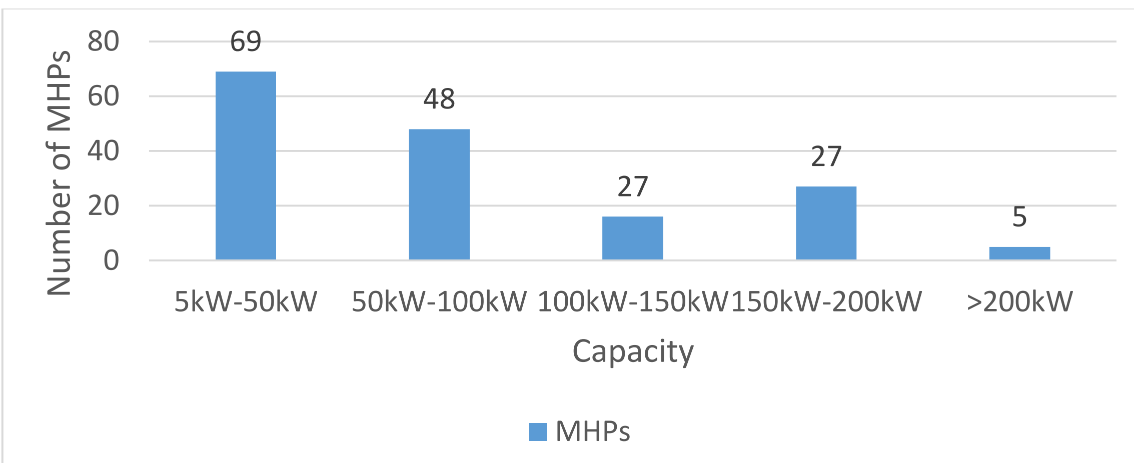

Figure 4.1.1 Capacity Range of MHPs

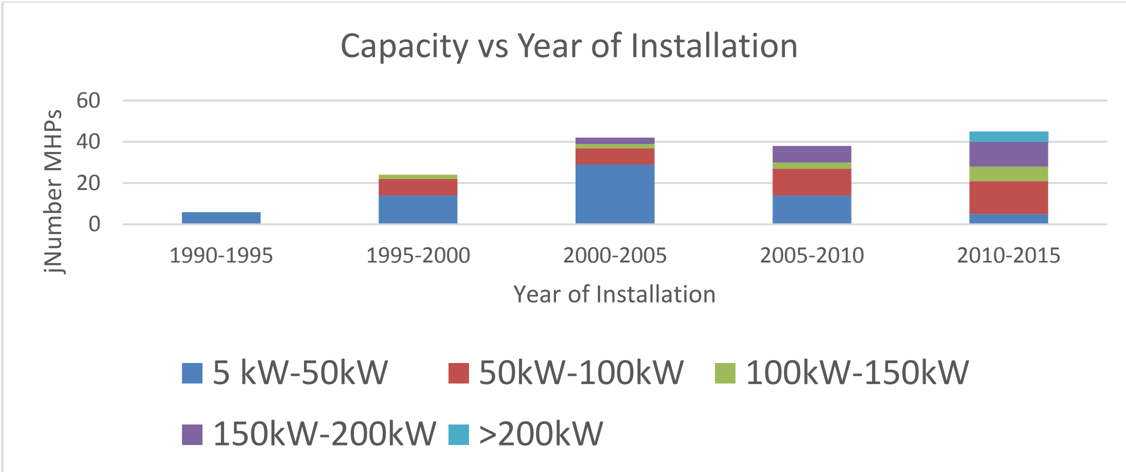

Figure 4.1.2 Capacity vs year of Installation

It is evident from Fig 4.2 that initially between the years 1990-2000 the focus was primarily on low capacity MHPs as the industry was new and organizations lacked the expertise. With the passage of time and the organizations gaining more experience the focus shifted toward high capacity MHPs between 2005-2015.

4.1.2 Current Status of MHP Plants

Total Number of Installed MHPs	**165**
Currently Functional MHPs	101 (63%)

.NO.	VILLAGE	Current Status of the Project	YEAR OF INITIATION	BENIFICIARY HOUSE HOLDS	**TOTAL Cost in Rs**	CAPACITY KW
1	SHINTHERY	Functional	1998	120	867,105	24
2	DAMEL NISAR	Non-	1998	60	896,662	20

Abandoned/Non Functional MHPs	64 (37%)

Table 4.1 Current Status of MHPs

With the passage of time 64 plants have become non-functional due to various reasons. The total number of functional plants is 101 (Table 4.1)

The details of all the 165 MHPs installed and Chitral is given in table below.

		Functional				
3	KAMSAI	Non-Functional	1998	120	975,653	40
4	ZARIN BAGH	Non-Functional	1999	100	1,049,250	15
5	DAMEL NISAR	Functional	2000	60	745,787	20
6	Arandu	Functional	2009	400	17,270,319	200
7	NAGAR	Non-Functional	1996	45	554,683	50
8	NAGAR	Non-Functional	1996	55	468,687	30
9	ASHIRATE	Functional	1997	45	630,427	30
10	LOTINGA	Functional	1998	63	882,809	30
11	BARADAM	Non-Functional	1998	80	1,022,509	12
12	SHAREDEHS	Functional	2000	157	1,577,669	50
13	DAMIK JINGIRATE	Non-Functional	2002	75	1,123,023	50
14	ZUGUNIK	Functional	2003	146	2,041,283	50
15	Birir	functional	2008	220	5,767,118	75
16	DAKHANANDEH	Non-Functional	1991	32	297,963	12
17	SAHAN BALA	Non-Functional	1993	37	282,689	10
18	KALASHAN DEH	Functional	1993	70	299,276	15

	ANIZH					
19	DARKHANANDEH	Non-Functional	1993	41	326,576	8
20	SAHAN BALA	Non-Functional	1994	36	300,926	12
21	SHEIKHANANDEH BUMBORATE	Functional	1994	48	312,879	12
22	DARKHANANDEH	Non-Functional	1994	16	203,134	15
23	BRUN BUMBORATE	Functional	1997	120	509,699	30
24	KRAKAR	Non-Functional	1997	59	508,550	30
25	BIRIR	Non functional	1998	40	515,358	15
26	RUMBOOR	Non-Functional	1999	80	1,385,960	20
27	SHEIKHANANDEH RUMBOOR	Functional	1999	124	1,465,170	50
28	PAHLAWANAN DEH	functional	1999	20	586,482	7
29	SHEIKHANANDEH BUMBORATE	Non-Functional	2000	68	1,150,442	50
30	PAHLAWANAN DEH	functional	2001	108	998,593	
31	BIRBOLAK BROZE	Non-Functional	1996	34	369,539	10
32	KORAGH	Non-	1993	112	742,715	30

		Functional				
33	RESHUN	Non-Functional	1994	200	633,475	50
34	RESHUN GOL	Non-Functional	1995	101	532,282	40
35	BILPHOK	Functional	1997	84	949,565	40
36	THINGSHEN	Non-Functional	1999	30	458,706	12
37	KUJU BALA	Non-Functional	1993	44	315,987	10
38	JUGHOOR GOLE	Functional	2001	36	900,865	
39	BURI MIANDEH	Functional	1997	32	539,220	24
40	BURI PAYEEN	Functional	1997	60	527,808	30
41	KALKATAK	Non-Functional	1997	95	325,395	30
42	BURI BALA	Non-Functional	1997	56	767,029	40
43	KALKATAK	Non-Functional	1998	25	828,846	7
44	Beshgram	Functional	2008	363	10,847,548	150
45	Sunich	Functional	2008	170	7,926,423	125
46	Susoom	Functional	2010	260	9,644,500	100
47	Kiyar	Functional	2010	170	10,042,805	100
48	SHERSHAL	Functional	1993	60	318,157	30

49	SHAH	Functional	1993	40	306,864	50
50	HERTH KARIMABAD	Functional	1995	340	1,157,902	50
51	SUSOOM	Non functional	1995	361	984,490	90
52	SUNICH	Non-functional	1995	70	347,000	30
53	HINJEEL	Non Functional	1996	86	597,063	30
54	BOKHTOLIGOLE	Non Functional	1997	84	1,132,483	50
55	KULOOM	Non Functional (Upgraded)	1998	304	1,461,464	50
56	HINJEEL	Functional	2002	139	3,072,004	75
57	SEWAKHAT	Functional	2003	60	1,305,012	50
58	Droneel Karimabad	Non Functional	2004	50	3,216,500	
59	KHOT PAYEEN	Functional	1994	80	569,962	50
60	KHOT BALA	Functional	1995	50	328,795	25
61	KHOT PAYEEN	Functional	1995	257	3,600,693	160
62	SORECH	Functional	1996	20	460,875	20
63	SORECH	Functional	1996	170	999,940	64
64	MORECH	Non Functional	1996	202	996,940	50

65	Khot Torkhow	Functional	1997	458	3,902,987	124
66	UJNU	Functional	1999	30	727,314	5
67	KOGHOZI	Functional	1992	32	259,043	12
68	KOGHOZI	Functional	1993	45	269,278	30
69	KOGHOZI	Functional	1994	60	520,295	30
70	MULEN BARENIS	Non-Functional	1994	32	304,027	15
71	MROI BALA	Non-Functional	1997	137	1,991,527	66
72	KOGHOZI	Non-Functional	1997	274	1,043,757	50
73	PASTI	Non Functional	1998	70	1,546,388	30
74	PRAYET PAYEEN	Non-Functional	1999	240	2,060,537	50
75	Koghuzi	Functional	2009	200	6,947,311	125
76	Istore	Functional Ongoing	2014	125	53,814,891	136
77	GOLBIYAR	Non-Functional	1995	85	333,051	15
78	MORDER	Non-Functional	1995	150	980,000	50
79	BARUM KAGH	Non-Functional	1997	125	1,099,846	50
80	TORI KOSHT	Non-	1997	120	1,019,847	50

		Functional				
81	Balim Laspur	Functional	2007	240	5,843,657	75
82	MIRAGRAM NO.1	Functional	1996	177	970,000	50
83	BALEEM	Non Functional	1997	246	1,198,986	75
84	RAMAN	Functional	1998	165	1,162,465	40
85	BROK	Functional	1998	180	1,320,203	50
86	GASHT	Functional	1998	135	1,213,361	50
87	SHAHIDAS	Functional	1998	40	616,263	24
88	SONOGHOR	Non-Functional	1998	50	532,613	7
89	AWI	Functional	1999	72	1,293,679	20
90	AWI	Functional	1999	87	1,101,057	30
91	SOR LASPUR	Functional	2002	285	1,344,933	50
92	Raman Hercheen	Functional Ongoing	2011	1025	87,839,935	600
93	Begusht	Functional	2008	200	4,857,690	100
94	Zheture	Functional	2008	280	5,385,111	100
95	Yurjogh	Functional	2008	340	6,812,441	150
96	Merdin	Functional	2009	350	10,190,583	110
97	Waht	Functional	2009	138	7,065,425	100
98	PARABEG	Functional	1983	70	89,411	20
99	BEGUSHT	Non	1995	160	1,212,929	100

		functional				
100	YOURJOGH	Functional	1995	180	1,348,485	100
101	GOBORE	Non Functional	1995	36	543,900	30
102	BIRZEEN	Functional	1997	198	1,175,625	100
103	PARABEG	Functional	1997	248	1,196,525	100
104	MEHRDIN	Non Functional	1997	73	820,325	50
105	ZHITUR	Non Functional	1999	250	1,490,252	50
106	WAHT	Non Functional	1999	150	1,471,506	50
107	MUNOOR	Functional	2000	142	1,442,264	50
108	Overik	Functional	2007	180	5,496,573	50
109	ShahSalim	Functional	2008	55	2,958,417	50
110	Birzeen	Functional	2010	262	15,030,937	200
111	Diezg	Functional	2008	362	10,679,113	200
112	CHAPALI	Functional	1997	118	1,644,318	50
113	MASTUJ	Functional	1997	65	511,637	24
114	CHUINJ BALA	Non-Functional	1998	229	1,346,250	50
115	MASTUJ	Functional	1998	180	1,509,291	40
116	CHINAR	Functional	1999	120	1,153,627	
117	KHUZH BALA	Functional	1999	200	2,155,427	40

118	GHORU	Functional	1999	136	1,385,240	40
119	PARI MALI	Non-Functional	1999	68	1,532,237	
120	KHRUZGH	Functional	2002	208	2,323,403	75
121	KHUZ	Functional	2003	84	1,277,421	20
122	SAHT PAYEEN	Non-Functional	1993	44	324,319	12
123	SAHT PAYEEN	Non-Functional	1994	65	409,910	15
124	RIRI	Non Functional	1995	75	833,064	50
125	SHABRONZE	Non Functional	2006	206	3,030,385	50
126	Shagram	Functional	2008	465	11,519,746	100
127	SHAGRAM	Functional	1994	376	2,233,711	100
128	RAYEEN	Functional	1995	46	311,100	10
129	RAYEEN	Functional	1995	45	294,464	10
130	WERKHOP	Non Functional	1996	25	284,090	5
131	MELP	Functional	1998	230	1,452,490	30
132	MELP	Functional	1999	115	1,924,410	30
133	MELP	Functional	1999	101	1,164,190	30
134	SHOTKHAR	Functional	1999	120	812,892	20
135	MADAKLASHT	Functional	1995	241	976,635	50

136	KOTIC	Non-Functional	1997	20	510,148	24
137	TAR	Non-Functional	2000	50	1,130,493	60
138	MADAKLASHT	Functional	2001	200	1,751,258	60
139	Iezh Garumchashma	Functional	2007	350	1,884,975	75
140	Arkari	Functional	2008	290	16,344,036	250
141	Momi	Functional	2008	215	11,245,450	150
142	HASSANABAD	Functional	1993	50	296,633	20
143	ARKARI	Functional	1995	450	1,574,990	150
144	OCHUGOLE	Functional	1996	22	355,845	20
145	MOMI	Functional	1997	150	937,705	50
146	SHAGRAM	Non Functional	1997	135	1,138,773	50
147	MURDAN	Functional	1997	130	862,684	50
148	EIZH	Non functional (upgraded)	1998	158	1,242,271	50
149	BESTI	Functional	1998	172	1,418,320	50
150	RUJI	Functional	1999	48	1,716,829	20
151	SHALI	Non Functional	1999	90	633,550	40
152	MIZHIGRAM	Non Functional	2000	40	982,901	24

153	Narkorate/Kandojal	Functional	2000	149	1,500,614	50
154	MOGH	Non Functional	2002	141	1,939,196	75
155	MOGH	Functional	2002	101	2,742,003	75
156	OVEER	Functional	2002	30	1,104,392	50
157	Shoghore	Functional Ongoing	2011	968	66,351,351	500
158	Oveer Arkari	Functional Ongoing	2014	156	15,214,642	125
159	Terich bala	Functional	2007	196	7,059,073	75
160	Zondrangram	Functional	2009	415	18,809,841	250
161	UNAWICH	Functional	2006	142	2,901,185	50
162	POWER	Functional	1995	312	1,944,600	140
163	BREP	Non Functional	1998	46	591,228	7
164	BREP	Non Functional	1998	45	670,719	7
165	GAZEN	Functional	2000	63	1,611,414	50

Reason of Non Functionalities

With the passage of time 65 MHP have become non functional in Chitral. The reason for non-functional

Number of MHPs	Reason of Non Functionality

30	Natural Hazards(Earth Quake , Avalanche, Floods)
14	Operation and Maintenance Issues
20	Installation of Reshun MHP by SHYDO

Table 4.2 Reason of Non-Functionality

4.2 Efficiency of Locally Manufactured Cross Flow Turbines

4.2.1 Cross Flow Turbine

The turbines used in the mini hydro plants installed in Chitral are cross flow turbines manufactured disks.[1].Cross flow turbines consists of a conical draft tube which creates a pressure below atmosphere in the turbine chamber. Air is admitted into the chamber through an air inlet valve which is adjustable and is used to control the pressure. When there are sand particles in the water entering the turbine then cross flow turbines are susceptible to wear. The runner of cross flow turbine is self-cleaning and generally the maintenance is less complex than other turbines. The shape of the blades helps the water to transfer some of its momentum on each passage before falling away with little residual energy.[2] Although Cross Flow turbines are less efficient than modern day turbines but they can operate at larger water flows and lower heads. A typical Cross flow turbine is shown in Fig 4.2

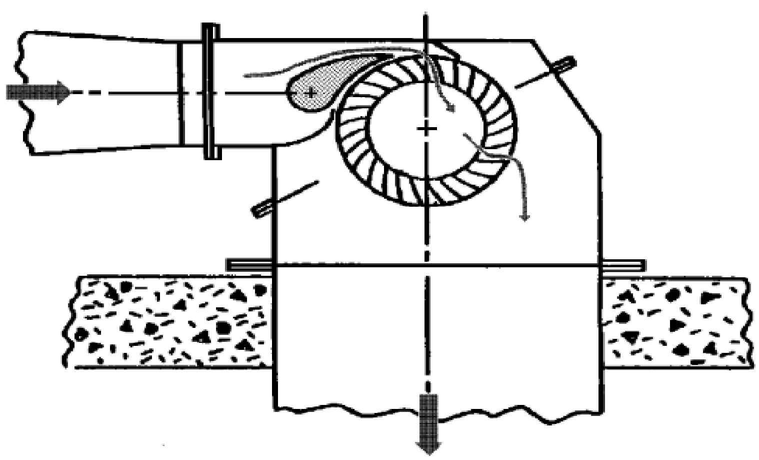

Figure 4.2 Cross Flow Turbine[1]

4.2.2 Turbine Efficiency

A significant factor in the comparison of different turbine types is their relative efficiencies both at th conditions. Typical efficiency curves are shown in Figure 4.2.1 .An important point to note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Cross flow and Francis turbines falls away more sharply if run at below half their normal flow.

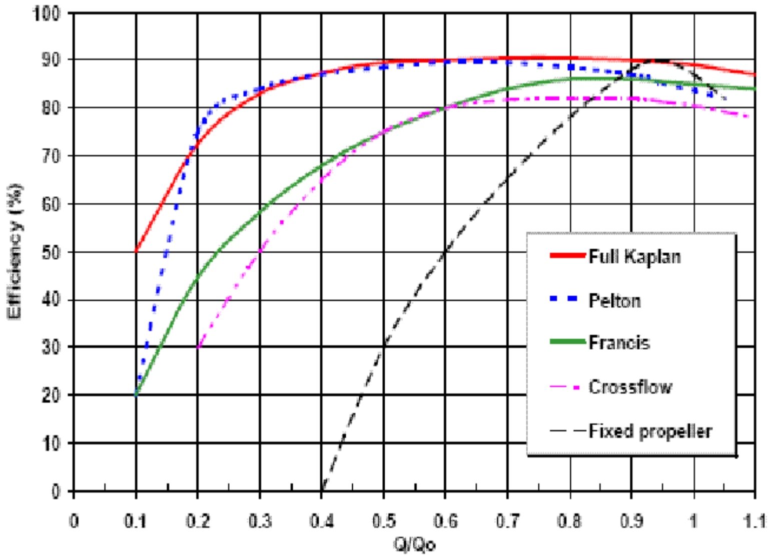

Figure 4.2.1 Efficiency Comparison of different turbines at reduced Flow Rates[3]

4.3 Turbine efficiency testing of 4 MHP sites in Chitral

The formula given below was used for calculating efficiency of cross-flow micro-hydro turbines in three different MHP plants installed in Chitral.

$$\eta = \frac{P}{\rho g Q H} \times 100 \quad \ldots\ldots\ldots\ldots\ldots (1.1)$$

P = mechanical power produced at the turbine shaft (Watts),

η = hydraulic efficiency of the turbine,

ρ = density of water (1000 kg/m3),

g = acceleration due to gravity (9.81 m/s2),

Q = volume flow rate passing through the turbine (m3/s),

H = effective pressure head of water across the turbine (m).

Qo =Hydro turbine maximum working flow rate

The value of ρ and g remained constant therefore the value of variable Power (P), Effective Head (H), and Flow rate (Q) needed to be evaluated. Effective head is net head at the turbine inlet, after accounting for loss head due fluid friction.

The following equipment were used for calculating flow rate, head and power.

1. Flow meter
2. Pressure transducer
3. Power meter
4. Dummy load

The dummy load used in the efficiency measurement process was a 135kVA resistive load that could be corresponding to the above two values of loads. This is because the load controller would automatically adjust the varying flow to suit the value of the load connected to it. In the absence of a load controller, as many readings as desired were possible. ELC was installed in some sites so there was no need to connect the dummy load. On other sites due to poor and lose connections in control panel it was difficult to connect the dummy load cable with it. Little disturbance in the panel could have damaged the whole cabling system.

4.3.1 Overick MHP

The turbine was at this site was installed in 2008.The population of this village is in excess of 2000 and the system is 69.11% at Q/Qo = 0.86. To get maximum efficiency, the system must be operated at this condition. The variable flow rate the influenced all other parameters of the system i.e. head, power output. Based on the values of these parameters efficiency was calculated and plotted in Fig 4.3.1

Table 4.3.1 Site Parameters Overick

Flow Rate(m^3/s)	Q/Qo	Head (m)	Active Power (kW)	Efficiency, η
0.3	0.7	21.4	30.6	61.58
0.33	0.77	21.8	39.8	67.55
0.35	0.81	22.4	41.1	66.36
0.37	0.86	22.6	44.5	69.11
0.4	0.93	22.6	41.6	58.92
0.41	0.95	22.5	44.8	60.4
0.43	1	22.1	39.1	49.63

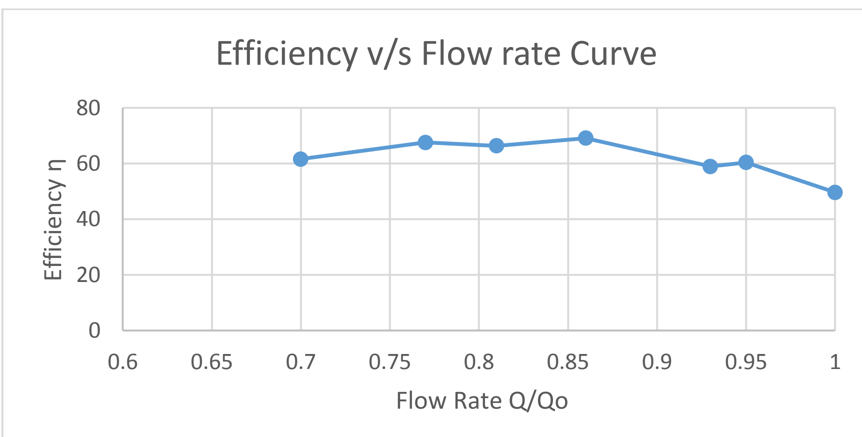

Figure 4.3.1 Efficiency Curve Overick site

The efficiency curve determined in the Overik site data somewhat resembles the actual efficiency curve (Fig 4.2.1) but there are marked deviations. The general plot of efficiency vs. normalized flow rate reaches its peak around Q/Qo=80%. The maximum efficiency is about 69%. Then the curve starts to dip as the efficiency goes on decreasing while the flow rate increases to its maximum value. Before the highest point is reached by the efficiency curve, the trend is an increase in efficiency with an increase inflow rate.The trend of the plot before and after peak value is almost similar to the general trend. The curve plotted actually shows an exploded view of one section or part of the entire curve that which is in the normalized flow rate range of 0.7-1.00. If this trend is interpolated, it will closely resemble the actual trend. The reason for the anomalies in the above graph are due to varying pressure head ratings and rapidly fluctuating power readings which has caused the curve to sway from the general trend.

4.3.2 Site 2 Birir MHP

Power house is located at Nosh Bru, Birir. There are approximately one hundred & seventy five (175) houses in the area and all of them are being supplied electricity by this power house. The population of the area exceeds 1750. The type of turbine installed is Cross-Flow. The potential of hydropower generation is 75kW and the percentage of potential used is 28% approximately at the prescribed date. Average units used are 225.5. Neither ELC nor MLC was installed at the site.

Efficiency was calculated by varying the flow. The flow was controlled manually; MLC was not installed at the site. Maximum efficiency of the system is 54.42% at Q/Qo = 0.94. To get maximum efficiency, the system must be operated at this condition. System was analyzed by varying flow rate. The variable flow rate influenced all other parameters of the system i.e. Head, power output etc. Based on the values of these parameters in Table3 efficiency was calculated and plotted in Fig 4.3.2.

Table 4.3.2 Site Parameters Birir

Flow Rate (m^3/s)	Q/Qo	Head (m)	Measured Active Power (kW)	Efficiency η
0.31	0.86	10.1	14.22	51.61
0.32	0.89	10.6	15.02	52.72
0.33	0.92	11.7	17.81	54.27
0.34	0.94	13.15	19.22	54.42
0.34	0.94	12.8	19.12	53.58
0.35	0.97	14.4	20.9	53.85
0.36	1	12.8	19.05	53.69

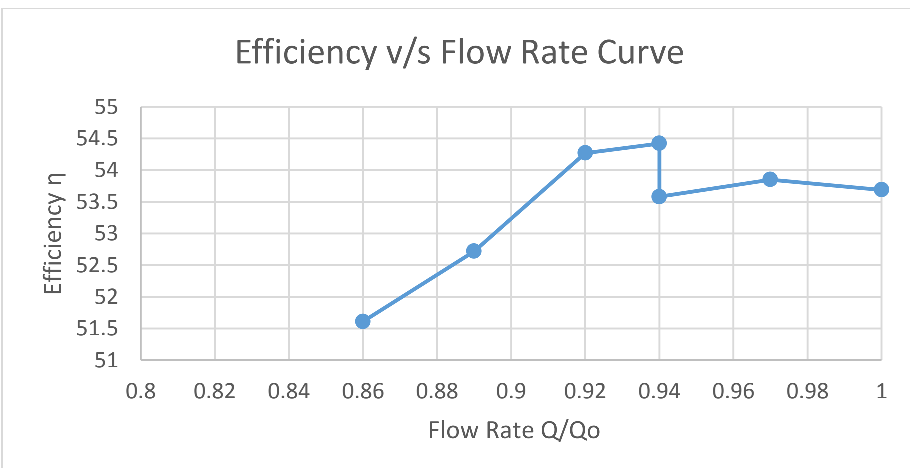

Figure 4.3.2 Efficiency Curve Birir site

This curve is sort of a magnified view of the actual curve and it covers only the 0.86-1.0 part of the normalized flow range. The plot shows a maximum efficiency of 54.42% at Q/Qo = 94. The curve is nearly horizontal in this portion, as expected, but shows a peak value at a flow rate much larger than what is expected. The reason for this is the dubious pressure head readings in Birir, which is due to the fact that the pressure transducer gauge could not be properly fit on the turbine since there was no proper place to put it. The pressure gauge mounting on the turbine had initially been closed with a twig and hence air used to fill the channel. The old and outdated distribution box also did not aid in taking power readings and thus a large range of readings could not be taken.

4.3.3 Izh MHP

The area where the turbine site is located is called Izh, and the site itself is called Narai. There are approximately two hundred (300) houses in the area and all of them are being supplied electricity by this turbine house. There are 312 connections in which 12 are commercial and 300 are to the houses. The population of the area averages 2400 (8 person per house). The type of turbine is Cross Flow. The potential of hydropower generation is 80KW.

The system was analyzed by varying flow rates. The parameters are shown in (Table 4.3.3) and the based on these parameters the efficiency v/s flow rate curve is shown in

Fig 4.3.3.

Table 4.3.3 Site Parameters Izh

Flow Rate (m^3/s)	Q/Qo	Head (m)	Measured Active Power	Efficiency η
0.35	0.65	25.45	26.1	29.9
0.42	0.78	25.04	32.18	32.04
0.45	0.83	24.9	41.29	38.39
0.51	0.94	24.4	45.18	36.6
0.52	0.96	24.3	53.64	45.45
0.54	1	23.7	67.06	53.36

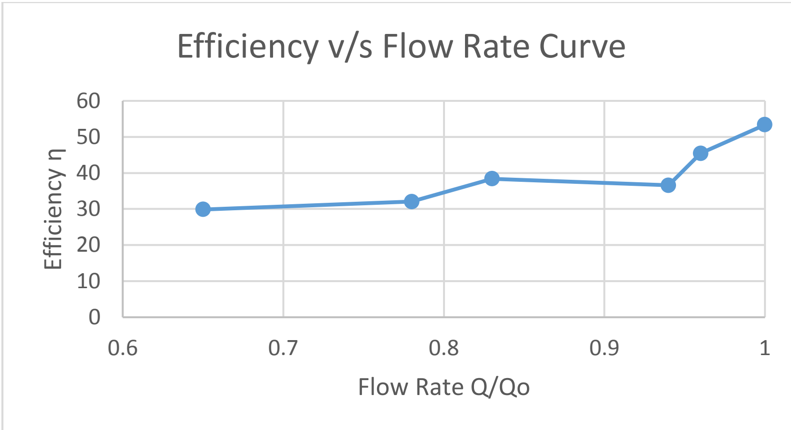

Figure 4.3.3 Efficiency Curve Izh site

This efficiency curve deviates largely from the original efficiency curve (Fig.4.2.1) because of many shortcomings present on the turbine site. The curve shows a maximum efficiency value of 53.36% at nearly the maximum flow rate i.e., at Q/Qo = 1.0.There was a genuine difficulty in taking power readings because of the dilapidated condition of the distribution box and the wires coming out of the generator, which themselves form a source of resistance for the flowing current and since there is a drop of potential across these wires, the measured power output readings are then affected. The generator was Chinese made and an old one. There was no place on the turbine to install the pressure transducer and hence welding was done on the spot to rectify the problem. The clearance introduced between the pressure gauge nut and the mounting lead to air being forced into the system, thus leading to errors in the values of pressure head.Even though a sufficient number of readings were taken by varying the load (ELC on the site was not operational), the error in these readings due to the above mentioned factors lead to a curve which highly strayed from the original one.

4.3.4 Site 4 Bilphok MHP

The area where the turbine site is located is called Bilphok and is installed by PCRET (Pakistan Council for Renewable Energy Technologies). There were approximately two hundred & sixty (260) houses in the area and all of them were being supplied electricity by this power house. The population of the area averages 1820. The type of turbine is cross-flow. The potential of hydropower generation is 75kW and the percentage of potential used is approx. at the prescribed date. It was installed in July 2006. Based on the parameters in (Table 4.3.4) the efficiency curved was calculated and plotted as shown in (Fig 4.3.4).

Table 4.3.4 Bilphok Site Parameters

Flow Rate m^3/s	Q/Qo	Head (m)	Measured Active Power (kW)	Efficiency, η
0.21	0.56	19	6.02	15.22
0.22	0.61	19.2	7.66	18.64
0.23	0.64	19.4	10.88	25.4
0.26	0.72	19.33	14.12	29.7
0.28	0.78	19.4	23.42	45.87
0.36	1	18.9	28.75	42.51

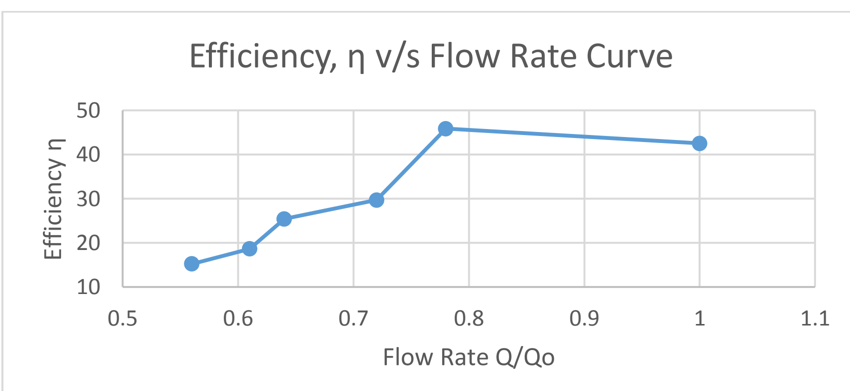

Figure 4.3.4 Efficiency Curve Bilphok site

The efficiency curve hugely strays from the curve normally expected for cross flow turbines (Fig3.2) in the flow rate range of 0.58-1.0. It shows the turbine maximum efficiency to be 45.87% which occurs at Q/Qo = .778. There were numerous hurdles faced at this site and hence it affected the overall results. The water flowing through the penstock in Bilphok was dirty and this hugely affected flow rate readings that were obtained using the flow meter. This explains why the maximum efficiency is obtained at such a high flow rate. The turbine and generator were worn out by repeated use and the generator in particular was of low efficiency. Hence, accurate readings could not be obtained.

4.3.5 Comparison of Efficiencies

The efficiency vs Q/Qo curves of all the sites is given on one graph (Fig 4.3.5). Overick had highest efficiency i.e., 69.1% because of its design, manufacturing installation and good maintenance. The turbine installed at Bilphok site had the smallest efficiency i.e., 45.87% because the there was a problem with the water reservoir due to which water drained away quickly. Therefore the desired head and flow rate were not available for efficient operation of the turbine.

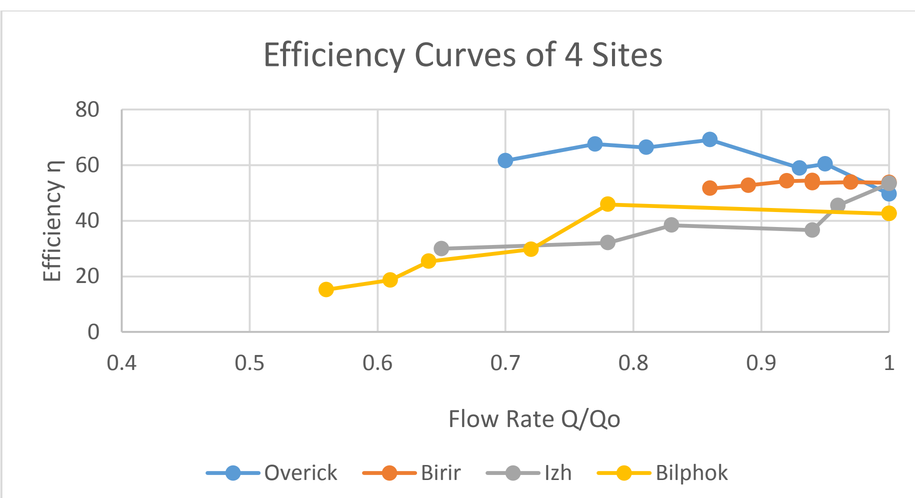

Figure 4.3.5 Efficiency v/s Flow Rate curves of all 4 sites

This is the first study of its kind to evaluate the performance of the Small Hydro Power plants installed in Chitral district of Pakistan. It was an interesting exercise to measure the efficiencies of some typical locally manufactured micro-hydro power plants which presented a clear picture of the existing situation and hence will help to assess the need for improving the design in order to increase the plant efficiency. With the passage of time the projects have been unable to meet the energy requirement demands due to increase in population and changes in usage patterns of electricity (from simply lighting to cooking, heating and supporting small enterprises). Most of the older projects have already completed their useful lives and have become in-efficient. The efficiency of the locally manufactured Cross Flow turbine used in the SHP plants is as compared to standard Cross Flow Turbines. A standard cross flow turbine has an efficiency of 83% to 85% [4]but the maximum efficiency of any SHP during this study was 69%.This suggests that the civil structures, electrical and mechanical equipment of these projects need up-gradation.

4.4 Financial Feasibility Analysis of MHPs

4.4.1 Data Tools Available for Financial Analysis

A variety of decision analysis methods and software based feasibility analysis and assessment tools have been developed for pre-feasibility and feasibility stage of an energy project. The following table provides summary of each available tool .(Fig 4.4.1) [5]

Table 4.4.1 Description of Available Assessment Tools

Assessment Tool		Features				
Product	Applicable Countries	Hydrology	Power & Energy	Costing	Economic Evaluation	Preliminary Design
HydroHELP	International			x		x
RETScreen®	International	x	x	x	x	
Virtual Hydropower Prospector	USA	x	x			
PEACH	France	x		x		x
Remote Small Hydro	Canada	x	x			
IMP	International	x	x			
Green Kenue	International	x				

4.4.2 RET Screen

A decision support system tool developed to help decision makers and planners in developing renewable energy projects is the RET Screen Clean Energy Project Analysis Software. It was developed by the contributions of experts from academia and industry. It is used worldwide for evaluation of energy production and savings from various types of renewable energy technologies [6]. It can also evaluate emission reduction and financial viability of energy projects. Hydrology and climate database can also be incorporated in this software [7]. This software is available online with a detailed user manual and a case study based training course. It is available in 26 different languages as well. The RET Screen Small Hydro Project Model with the software can be used world-wide to easily evaluate central-grid, isolated-grid and off-grid hydro projects, ranging in size from multi-turbine large, small and mini hydro installations to single-turbine micro hydro systems.

To-date, stakeholders have saved an estimated $2 Billion worldwide through the use of the RET Screen software, databases and related training material. More than 132,000 people in 222 countries now use RET Screen, and the number of people benefiting from this decision-support and capacity-building tool is growing at more than 900 new users every week [5].

RET Screen can of asses all types of renewable energy technologies (RETs) viability factors such as availability of energy at the project site, performance of equipment , initial costs, projects periodic costs, finance, income and saving, environmental credits etc. The meteorological data that is incorporated in the software includes the ground-based meteorological data and meteorological data derived from satellite. The hydroelectric model of RET Screen can be used worldwide. The same has been used for the financial feasibility analysis of 3 different MHPs in Chitral.

4.4.3 Financial Analysis of MHPs in Chitral

4.4.3.1 Site 1 Dinsk MHP

The site is located in Dinsk village of Tehsil Garamchashma in Chitral. The capacity of the site is 30Kw. The site has recently been completed under the Government of KPK funded Pakhtunkhwa Energy Development Organization (PEDO) project. The site is ready for inauguration and expected to be properly functional by October 2016.

Six worksheets are provided in the RET Screen small hydropower file.

1. Start Sheet
2. Energy Model Sheet
3. Cost Analysis Sheet
4. GHG Emission Analysis Sheet
5. Financial Analysis Sheet
6. Sensitivity Analysis Sheet

1. Start

This is the first worksheet of RET Screen file and contains information about the project like the location, type of energy project and type of analysis as shown in the (Fig 4.4)

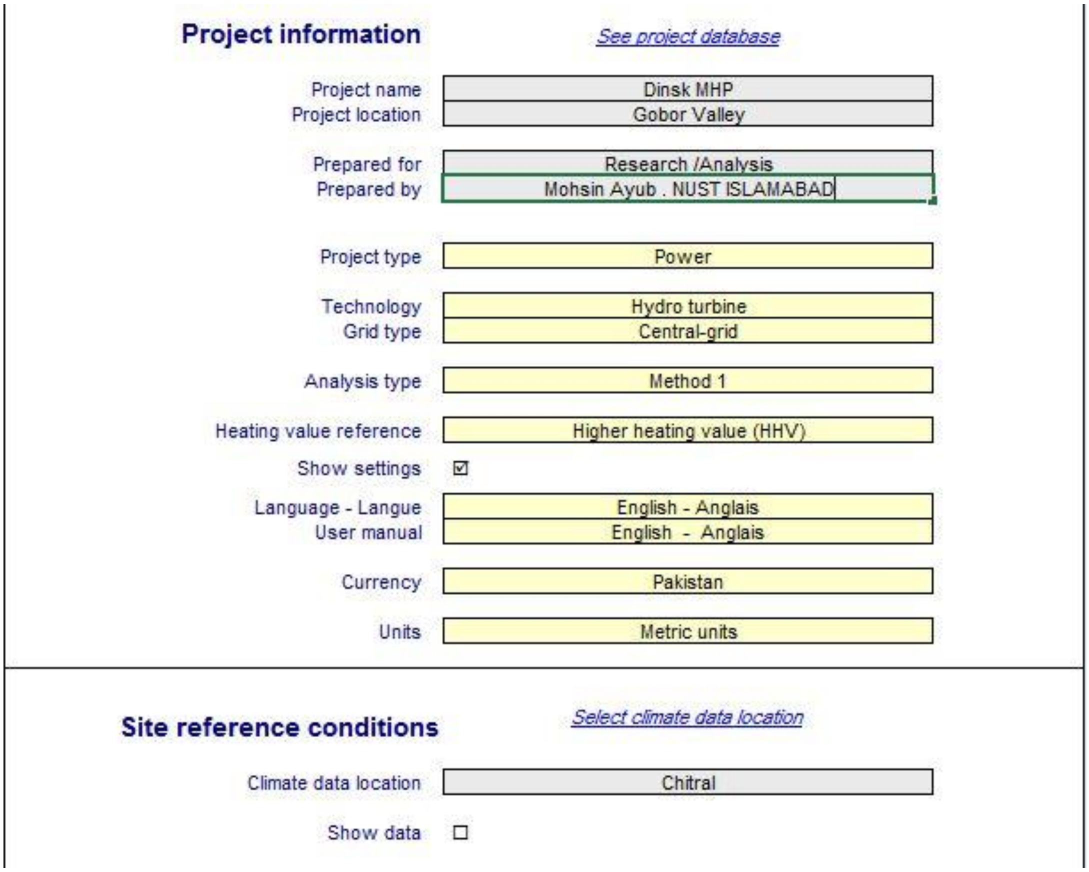

Figure 4.4 Start Worksheet of MHP Analysis

2. Energy Model

This worksheet requires the user to collect basic site details like latitude and longitude, available head and the design flow. Based on the available flow, design flow, the gross head and the efficiency RETScreen calculates the estimated energy delivered for MHP project (Fig 4.4.1)

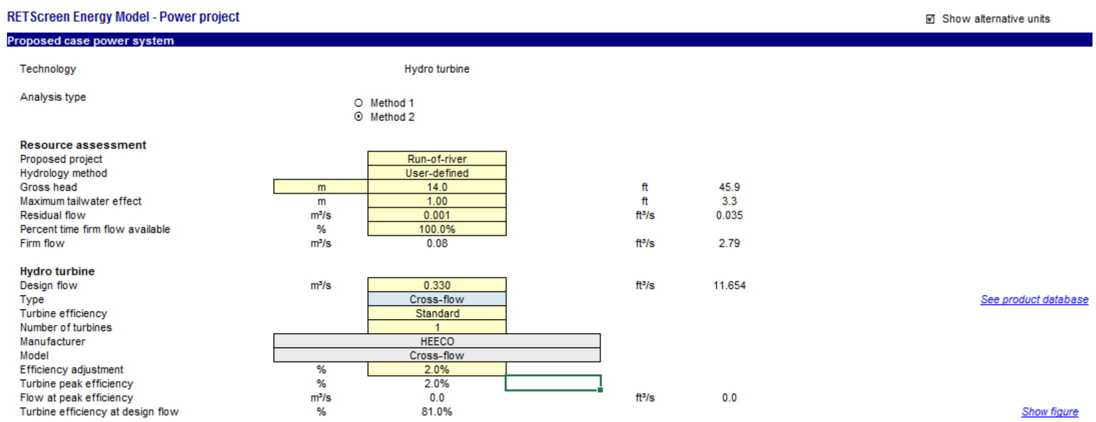

Figure 4.4.1 RET Screen Energy Model

The turbine efficiency is calculated at regular intervals of flow curve by RET Screen and the curve for power generation is generated Fig 4.4.2.

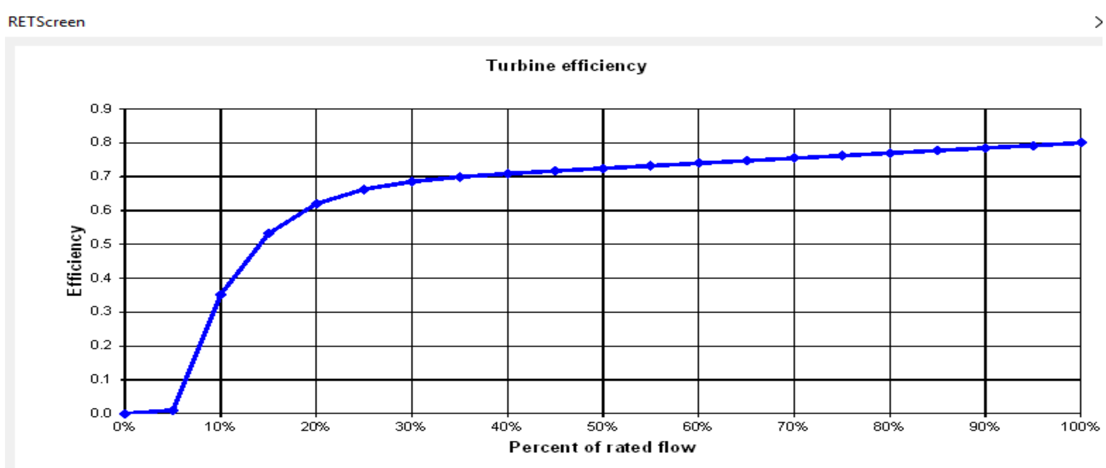

Figure 4.4.2 RETScreen generated Turbine Efficiency Curve

3. Cost Analysis

In this worksheet the initial cost and the annual cost involved in the project are taken into account and a detailed cost analysis is performed. The total initial costs given by the installing organization were PKR 68, 12,000. Out of this 1,670,500 is the cost of Electro Mechanical Equipment, RS 1,541,500 is the cost of Transmission and Distribution and RS 36, 00,000 was the cost of civil work. Generally for MHP projects the annual O&M cost is 10 % of the projects total initial cost.

Project costs and savings/income summary			
Initial costs			
Feasibility study	0.7%	PKR	50,000
Engineering	48.6%	PKR	3,600,000
Power system	50.8%	PKR	3,762,814
Balance of system & misc.	0.0%	PKR	0
Total initial costs	**100.0%**	**PKR**	**7,412,814**
Annual costs and debt payments			
O&M		PKR	60,000
Fuel cost - proposed case		PKR	0
Total annual costs		**PKR**	**60,000**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		PKR	0
Electricity export income		PKR	1,349,530
Total annual savings and income		**PKR**	**1,349,530**

Figure 4.4.3 RET Screen Cost Analysis

4. Emission Analysis

RET Screen estimates the amount of GHG that could be avoided by using a renewable energy source such as a MHP .The required data in this worksheet is the fuel source used. For this 30Kw MHP site the emission reduction is 44.2 tCO_2.

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2			Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	44.2	0.0			44.2		44.2
Net annual GHG emission reduction	44.2	tCO2	is equivalent to	18,992	Litres of gasoline not consumed		

Figure 4.4.4 RETScreen Emission Analysis

5. Financial Analysis

In this worksheet financial indices like year to year cash flow, the net present value and internal rate of return were calculated. All the calculations are based on 15.7% Pre-Tax Equity IRR. The simple payback is almost 5 years and equity payback is 6 years (Fig 8). The simple payback represents the length of time that it takes for a proposed project to recoup its own initial cost, out of the income or savings it generates. The simple payback method is not a measure of how profitable one project is compared to another. Rather, it is a measure of time in the sense that it indicates how many years are required to recover the investment for one project compared to another. The equity payback the length of time that it takes for the owner of a project to recoup its own initial investment (equity) out of the project cash flows generated.

The net present value calculated is RS 2,876,492 and the benefit to cost ratio is 1.39. The cash flow graph is shown in Fig 9 below.

Financial viability		
Pre-tax IRR - equity	%	15.7%
Pre-tax IRR - assets	%	15.7%
After-tax IRR - equity	%	15.7%
After-tax IRR - assets	%	15.7%
Simple payback	yr	5.7
Equity payback	yr	5.9
Net Present Value (NPV)	PKR	2,876,492
Annual life cycle savings	PKR/yr	337,872
Benefit-Cost (B-C) ratio		1.39
Energy production cost	PKR/MWh	4,497.82
GHG reduction cost	PKR/tCO2	(7,652)

Figure 4.4.5 RETScreen Financial Viability of Dinsk MHP

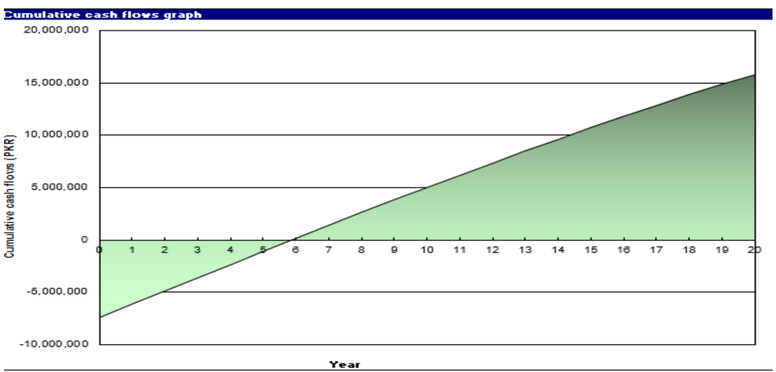

Figure 4.4.6   Cash Flow Graph of Dinsk MHP

The B-C ratio which is the ratio of the net benefits to costs of the project. Net benefits represent the present value of annual income and savings less annual costs, while the cost is defined as the project equity. Ratios greater than 1 are indicative of profitable projects The B-C ratio of the 30Kw Dinsk Gobor MHP calculated after the above analysis is 1.39 which is greater than 1 thus the MHP project is feasible for MHP based electricity rate of RS 6/ Kwh.

A similar analysis was performed for a 50Kw and 100Kw MHPs in Sunich and Susoom villages respectively.

4.4.3.2 Site 2 Sunich MHP

The parameters of this site are shown in Table 4.4.4

Capacity	50 Kw
Total Costs	PKR 31,12997
Households Connected	124

Table 4.4.3 Site Parameters Sunich MHp

Financial Analysis

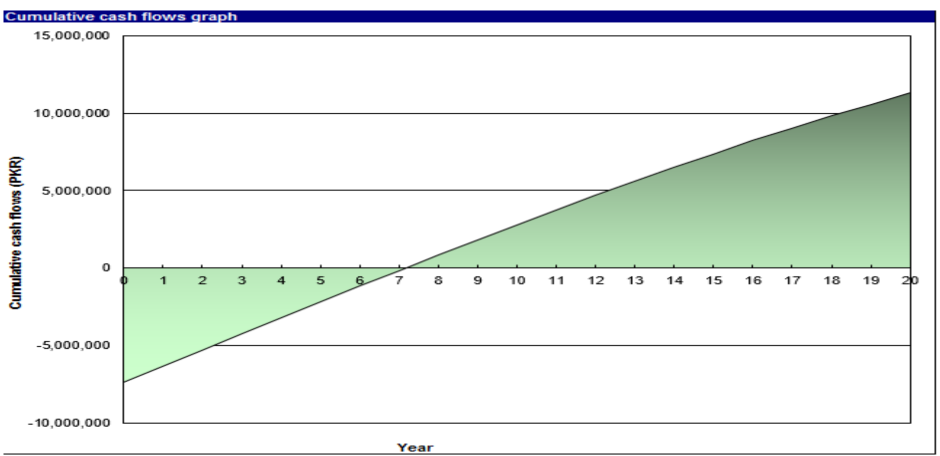

Figure 4.4.7 Cash Flow 50Kw Sunich MHP

Financial viability		
Pre-tax IRR - equity	%	12.0%
Pre-tax IRR - assets	%	12.0%
After-tax IRR - equity	%	12.0%
After-tax IRR - assets	%	12.0%
Simple payback	yr	7.0
Equity payback	yr	7.2
Net Present Value (NPV)	PKR	961,607
Annual life cycle savings	PKR/yr	112,950
Benefit-Cost (B-C) ratio		1.13
Energy production cost	PKR/MWh	4,497.82
GHG reduction cost	PKR/tCO2	(2,558)

Figure 4.4.8 Financial Viability 50Kw Sunich MHP

4.4.3.3 Site 3100Kw Susoom MHP

The parameters of this MHP site are shown in Figure 4.4.3.1

Table 4.4.3.1 Site Parameters Susoom MHP

Capacity	100Kw
Total Cost	PKR 99,24,810
Households Connected	260

Financial Analysis

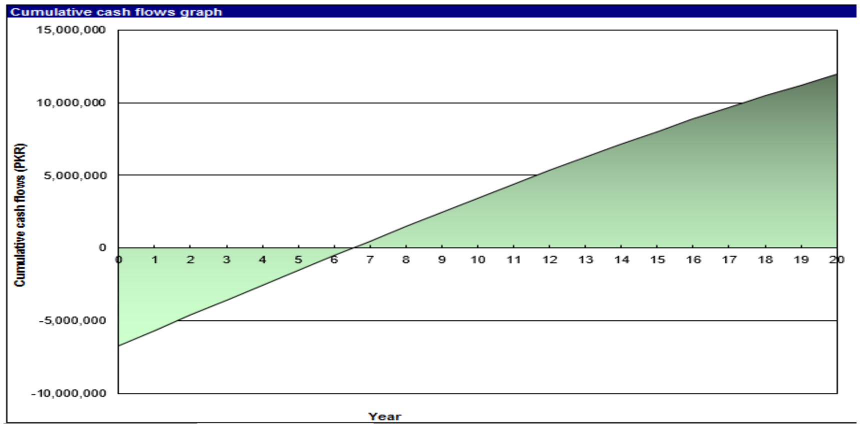

Figure 4.4.9 Cash Flow 100Kw Susoom MHP

Financial viability		
Pre-tax IRR - equity	%	13.6%
Pre-tax IRR - assets	%	13.6%
After-tax IRR - equity	%	13.6%
After-tax IRR - assets	%	13.6%
Simple payback	yr	6.4
Equity payback	yr	6.5
Net Present Value (NPV)	PKR	1,611,607
Annual life cycle savings	PKR/yr	189,299
Benefit-Cost (B-C) ratio		1.24
Energy production cost	PKR/MWh	4,158.38
GHG reduction cost	PKR/tCO2	(4,287)

Figure 4.4.10 Financial Viability 100Kw Susoom MHP

4.4 Comparison of Financial Parameters

Table 4.4 shows the comparison of 3 MHP sites evaluated using RET Screen.

Table 4.4 Comparison of Financial Parameters

MHP Site	Capacity	Payback Period	Benefit-Cost Ratio	IRR
Dinsk	30 KW	5.2 Years	1.39	15.7%

Izh	50 kW	6.4 Years	1.24	12%
Susoom	100 kW	7 Years	1.11	13.6%

The analysis of the projects shows the B-C ratio all the 3 MHP projects is greater than unity and the equity payback period is 5.2, 6.4 and 7 years respectively. Both these parameters indicates that the projects are financially viable at an electricity rate of just 6Rs/Kwh which is half the rate at which WAPDA is charging its customers for electricity.

Concluding the above analysis we can say that MHPs projects offer great opportunity for development of the country. They deserve to be high on the government's agenda as they are cheap, domestic and renewable. They also create business opportunity for private organizations especially in developing country like Pakistan. The decision makers may benefit from the analysis of RET Screen in evaluating various alternatives of hydro power projects.

4.5 Summary

To provide electricity to the geographically scattered population of Chitral a total of 165 MHP plants have been installed since 1985. These MHPs are providing electricity to the communities which are not connected to the national grid. The capacity of the MHP plants ranges from 5kW-250kW. Over 50% of the electrified population of Chitral is connected to these MHPs. Out of the total 165 MHPs 64 have become non-functional with the passage of time due a number of reasons. Apart from these install MHPs new projects are also being initiated by the Government as well as various NGOs to meet the total electricity demand of 35MW.

These MHP plants are cheap, reliable and dependent on domestic resource. The financial feasibility analysis of 3 different MHP plants using RET Screen showed that they are a financially feasible renewable energy projects. The two financial viability parameters, i-e Payback period and B-C ratio of the MHP plants generated by RET Screen confirms the claim of them being financially feasible. At an electricity export rate of 6Rs/kwh, which is half the price WAPDA is charging its customers, these MHP plants have a payback period ranging from 5 to 7 years depending on the capacity.

Almost all the MHP plants in Chitral have locally Manufactured Cross Flow turbines installed. The efficiency of these locally manufactured turbines when compared to international standards were very low. An ideal cross flow turbine has an efficiency of 85% at flow rate range of 80% -85%. The cross flow turbines manufactured in Pakistan have an average efficiency of 55 % – 65 % which is 20 % less than the standard turbine. And when the capacity of turbine increases the efficiency decreases for the locally manufactured turbines. This low efficiency of turbines is one of the reason that the generating capacity of an MHP plant is often less than its installed Capacity.

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Chapter 5

Management and Operation Mechanism of MHPs in Chitral

5.1 The MHP Management Committee

In community managed MHPs in Chitral the institution that defines and controls the governing rules is called the MHP Management Committee or the MC. Every village has its own respective MC and the members of MC are selected by the community members where MHP is installed. Generally an MC has the following important position apart from general members:

- *President:* is responsible for maintaining records of maintenance fund. He is the representative of the community in dealings with the funding organization and other matters outside the village. His signatures are necessary for using the maintenance fund.
- *Manager: He* is the one who calls meetings of the community and he leads the meetings. Collection of fee and payment of employees is coordinated by president of MC. He is also responsible to organize communal work of community in case of a major repair. He is also the undersigned in the use of maintenance fund.
- *Secretary: This* is another important position existing in most of the MHPs (not all). It is named treasurer in some MCs. The duties of his member are all related to financial matters.

The monthly fees are not collected by the head of the MC or the employees. The monthly bill is collected by the members of MC and generally members are responsible for specific areas. The MC held monthly meeting in which the members hand over the collected money to the manager of MC. The manager then release salary of the employees and takes decision on punishments and sanctions.

5.1.1 Main Responsibilities of MC

The members of MC have different duties and responsibilities as discussed above. The MC is responsible for organizing work of the employees and to generate financial resources for operation of MHP as well. The responsibilities of MC also varies from village to village but they can be summarized as:

- *Setting tariff System*
- *Collection on monthly bills and their proper utilization*
- *Realization and decision on punishment and sanctions on free riders*
- *Organization of man power for communal works*
- *To provide skilled and non-skilled labor for construction work*
- *To select employees and their supervision*
- *Payment to employees and other financial matters*

The responsibilities of MC members and rest of the community dis different in every village. The community member often participate in decision making process but the employee selection and the tariff is sole responsibility of the MC and rest of the community has no say in it. The sanctions and punishments are often decided at the early stage of the project by the whole community and enforcement of these sanction is the responsibility of MC. If a change in the rule is required the MC holds meeting with the entire community. The MC members are not paid for their services and they work voluntarily.

5.1.2 Employees of MC

Certain number of people are employed by the MC in every village. These members are selected by the community. The employs can be classified into four categories:

1. ***Operator***: every community employs an operator. The operator receives very basic training rom the installing authority and becomes responsible for every technical process. He supervises the machinery during operation. In some villages he is also responsible for tariff collection and even he is in charge of all financial matters in villages with no MC.
2. ***Watchman:*** The watch is responsible for channel. He observes the channel on daily basis and removes obstacles and looks for possible breaks in the channel. He also has to clean the forebay tank. In winters he along with operator is responsible to prevent the channel from freezing. The average monthly salary of an operator is around 2000 to 3000 depending on the size of the MHP and the number of households connected to it.
3. ***Lineman:*** Some villages with large number of households employ a lineman additionally. He is responsible for providing electric connections and maintaining transmission lines.
4. ***Meter reader:*** Only villages with meters installed employs a meter reader.

In majority of the projects flow and load control governors are missing. The operator has to manually control the flow of the water in order to keep the generator speed constant. He observes the voltage and frequency meters constantly. The operator has to stay inside the power house the whole night to check the meters and to observe the sound of the machinery and to adjust the water flow accordingly. Generator burn out is a very common problem noticed by the installing authorities and community members in many villages.

5.2 Billing Mechanism of MHPs in Chitral

Apart from the characteristic of a micro hydel that it has to be maintained by means of human resources, the system furthermore requires a considerable amount of financial resources which the community members have to afford. A major part of the money is collected through electricity fees, which are mainly used for paying the wages of the staff as well as for expenditures on the regular maintenance of the machinery. While the exact utilization of the funds provided by the community will be discussed in detail in the following two sections, the fee-collection systems in the different villages can be differentiated into four different billing policies.

1. Meter
2. Pure Flat Rate
3. Per Tube Light
4. Flat Rate plus fee for added tube light

The frequency of occurrence of these billing mechanisms and the detail is shown in Table 5.1.

Table 5.1 Billing Mechanism of MHPs in Chitral

Billing Mechanism	**Frequency of Occurrence**	**Amount Charged**
Meter	15 % (24 MHPs)	6 Rs/unit
Flat Rate	30 % (50 MHPs)	100-200 Rs/Month
Per Tube Light	20 % (33 MHPs)	20Rs/tube light
Flat rate plus fee for added tube light	35 % (58 MHPs)	100 Rs + 20 per added tube light

The most common practice in Chitral is to charge a flat rate for every household irrespective of the electricity consumed or some extra charges for added tube lights above a certain allowed number of tube lights. In 30% of the projects the fee is calculated by multiplying number of used tube lights with a certain fixed amount. The main element of billing in most of the villages is the number of tube lights used. While lightening being the most important other electrical appliances are also used in many villages. Generally there are no charges for any other electrical appliances other than TV.

The amount of flat rate and the rate of added tube light varies significantly across various MHP projects. The size of the project influences this pattern as the households connected to small project have to pay high prices to generate enough revenue to pay the staff and to generate maintenance funds.

Shops connected to an MHP are charged a special flat rate which is generally higher than the flat rate of connected households. Police stations, mosques schools and madrasas are free of charge.

5.3 Use of Collected Funds

The monthly electricity fees is collected by the EMC in the village. In some villages the operator has to go door to door to collect the bill at the end of the month. In others the community members go to the house of the manager of EMC to handover their electricity bills. The collected funds are basically used for three purposes:

5.3.1 Salaries

Each community employs at least one person for the operation of the micro hydel. As this assignment is a full-time job he receives a monthly salary. Depending on the number of employees and their wages, a village has to provide between Rs. 750 and Rs. 9,000 in funds every month.

5.3.2 Regular Maintenance

The maintenance of the electro- mechanical equipment needs a considerable amount of funds for purchasing, among others, grease, belts and bearings. With considerable variations between different villages, a community has to spend on average around Rs. 540 per month, dependent among other things on the age of the equipment and quality of the construction.

5.3.3 Emergency Maintenance

In the event of a breakdown of the micro hydel, financial reserves need to be available to afford the necessary repairs, especially for the electrical and mechanical equipment. In more than 20% of the villages a major breakdown of the electro-mechanical equipment happens at least once a year. Half of the break downs in the last three years were caused by a burn-through of the generator, which is responsible for almost two-thirds of all electro-mechanical breakdowns. Keeping the variations between the villages in mind, each community spends on average an additional amount of Rs. 3,500 per year on emergency maintenance

In order to bear these three sources of expenditures, in principal each community member has to contribute financial resources in two ways:

1. Every household has to afford the monthly electricity fees, which represent the Monthly Revenues of the project
2. Apart from the monthly electricity fees, in the initial stage each household has to pay a connection charge (between Rs 500 and 1,000) which will provide the basis for the Maintenance Fund as agreed in the Terms of Partnership (ToP).

5.4 Maintenance Fund

According to representative of AKRSP about 22% of the total villages that they have installed MHPs in have not established a maintenance fund although they agreed on it while signing the TOP. Majority of the villages with no maintenance fund are located in the lower part of Chitral district apart from the two MHPS managed by Kailash Community. The reason is the acceptance problem of AKRSP by Sunni and Pashtun dominated communities. In order to install an MHP in these villages' concessions were made in the ToP and establishment of a maintenance fund was dissociated.

Maintenance fund vary from village to village and without the complete analysis of the financial mechanism of each village the maintenance fun says very little about the overall financial profitability of a MHP project. The establishment and size of maintenance fund is often negotiated with the installing authority as a pre requisite for installing the project. So like other financial mechanisms it is not community made financial arrangement.

5.4.1 Importance of Maintenance Fund

It is obvious that communities having established a large Maintenance Fund have advantages: In the event of a larger repair, funding is readily available and in some isolated cases the Maintenance Fund is even enough for a future replacement of electro-mechanical parts. However, judging these projects financially more sustainable than those with no Maintenance Fund, would require the latter to evidently face more problems in financing repairs. This assumption could not be approved. The reason is that communities with no Maintenance Fund have different characteristics to the other villages. The existence of a Maintenance Fund is strongly influenced by the denominational setting. This fact also indirectly influences the size of the projects, as religious motivated tensions and reservations against AKRSP have hindered the motivation and cooperation of communities for obtaining larger project. The required money is either taken as a credit and paid back later on or collected through ad hoc levies. In that case only in very rare situations does every household pay the same amount of money; instead the people contribute according to their financial capacity. In the visited communities, these procedure have so far worked quite well, due to relatively small numbers of electrified households and there- fore relatively low organizational efforts. Apart from time lags between the occurrence of the damage and the allocation of funds, micro hydels managed by communities with no Maintenance Fund can on the basis of the collected empirical data not be considered being financially less sustainable per se than projects where such fund exits, due to their special conditions.

5.5 Other O&M Models

5.5.1 Community Based Power Utility

This is a new model introduced by AKRSP and has been successfully implemented by AKRSP in its 300kW MHP project in Ahmedabad Gilgit. Thereafter it has been introduced in Chitral also.

In this model a power utility has to be formed and registered with the company. Upon the completion of construction the Power Utility takes over the O&M of the project and becomes responsible for its maintenance and sustainability. Specialized training is provided by AKRSP which is the donor Organization to the technical staff responsible for O&M of T&D lines, E&M Equipment, tariff collection, meter reading and financial management. Annual and periodic audit of these utilities will be conducted.

5.5.2 Joint Management

Sarhad Rural Support Program (SRSP) has introduced this new concept of joint management by the community and funding organization. In this concept the funding organization is directly involved in the O&M of MHPs. However the ownership of the project always lies with the community. The organization provides technical assistance to the community for determining tariff, revenue collection and its utilization. The organization provides technical support during O&M of the project and also has its say in the Tariff collection.

5.5.3 Local leaseholders/operators

This is another O&M model in practice in other Asian countries. This model enables local operators as lease holders. It also ensures the involvement of communities to a manageable extend. It provides right incentives to the involved parties. Following are the rights and responsibilities of the involved parties according to this model:

The Community: The community proposes the local operator and lease the MHP to the operator for a certain period.it also supports the lease holder in tariff collection and labor intensive repairs. The community is also responsible for saving the lease money in an individual account and monitors the performance of the lease holder. The community is also responsible for maintenance and repairs of >100000Rs

Local Leaseholder: Continuous operation of the MHP is the responsibility of the lease holder. Monthly meter reading, tariff collection, maintenance of <100000Rs and monthly payment of lease are also the responsibility of the lease holder according to this model.

The Donor Organization: Designing the system and handing its ownership to the community is the basic responsibility of the installing authority according to this model. Besides it also has to provide technical support for the professional operation and maintenance. Sets up standards for operation and tariffs, establish a market based support mechanism that is within easy access operator operators and the user community.

5.6 Summary

In community managed MHPs in Chitral the institution that defines and controls the governing rules is called the MHP Management Committee MC. There are different employs of the MC i-e Operator, Lineman, Watchman and meter reader each having their own responsibility. Every village has its own respective MC. The billing Mechanism of MHPs in Chitral is decided by the MC and can be classified into four different billing policies, i-e Meter, Pure Flat Rate, Per Tube Light, Flat Rate plus fee for added tube light. The fund collected by the above mechanism is used for different purposes like salaries for the employs and maintenance of the MHP plant. The general financial mechanism can be explained by the following flow chart in Fig 5.6

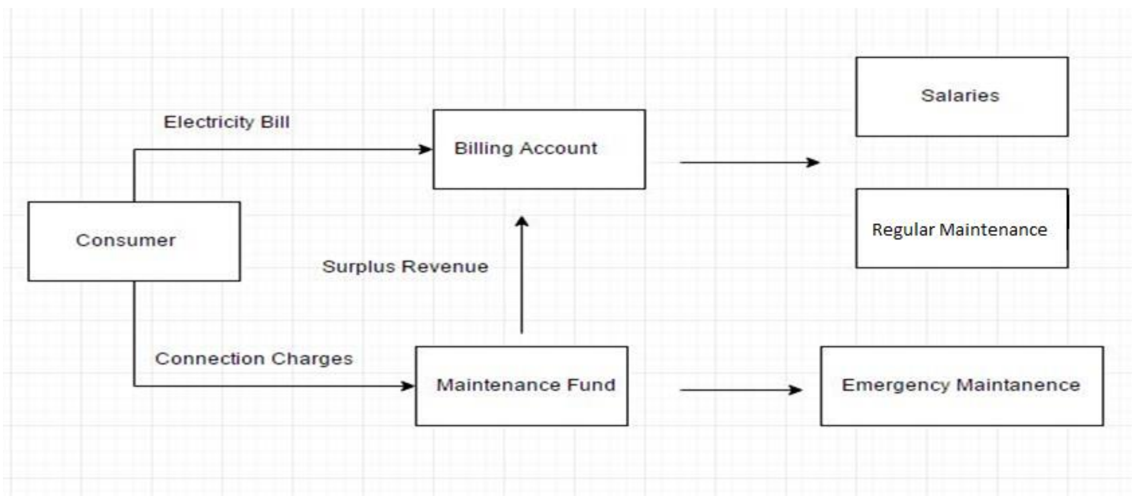


Figure 5.6 Financial Mechanism of MHPs in Chitral

Chapter 6

Socio-Economic Impacts of MHPs

Access to electricity contributes to poverty alleviation and to sustainable human development. Electricity is essential for the provision of quality community services especially of educational and health services and of water supply [1]. It has also tremendous positive impacts on rural households, particularly on children and women who bear the responsibility and hardship of main household work [2]. Access to lighting, information and communication improves the living conditions of each household, reduces migration to the urban centers and improves the attractiveness of the community for well-educated and professional service people like teachers, doctors [3].

6.1 Impacts of MHPs on Chitral Region

<u>Economic Benefits</u>

6.1.1 **Savings on Fuel**

Primary fuels used for space heating and cooking in Chitral are fuel wood and kerosene oil. To study the effect of electrification on the expenditure on these two sources a sample size of 50 houses were taken in four different villages. The results are shown in Table 6.1 and Table 6.2.

Village	Number of	Number of	Fuel wood	Value of Fuel

	Households	Households using Electric Heaters	saved 0.6 ton/HH	Wood at Village RS 7000/Ton
Harchin	1100	100	60	420000
Gobor	600	170	102	714000
Izh	730	67	40	210000
Shoghore	430	44	27	189000
Total	2870	391	229 Ton	RS 1533000

Table 6.1 Savings on Fuel Wood

Based on these 4 villages we estimated the amount of fuel wood saved in all 59 Villages where MHP of capacity large than 100 kW is installed. The result was 3378Tons. This means that after electrification of villages in Chitral, 3378 Tons of precious fuel wood is saved annually. This is the amount of fuel wood used for space heating only. The amount saved by using electric stoves is other than this figure.

Similarly the amount of kerosene oil saved was also calculated for the villages and is shown in Table 6.1.2.

Kerosene Consumption	Low	Medium	High	Kerosene oil saved Per month
Amount saved in summer	272 Rs/month	450Rs/month	580Rs/month	34 L/month
Amount saved in winter	453.6Rs/month	635Rs/month	740Rs/month	60 L/month
Total	4169Rs/year	6345/year	7760/year	538L/year

Table 6.1.2 Savings on Kerosene oil

6.1.2 Job Creation

The installation of an MHP is a huge economic activity for the beneficiary communities. Both skilled and unskilled labor is required in the construction and installation and common practice is to employ labors from the beneficiary community [4]. Depending on the capacity of MHP there are 4 to 8 new jobs available after the completion of the project. Each EMC employs a lineman, an operator, two meter readers and fee collector. There is an accountant to manage the finances as well. So job creation for the local villagers is another advantage for the community apart from getting electricity.

6.1.3 Small Enterprise Development

The provision of electricity to the remote villages of Chitral has also enable the interested individuals to start businesses and small enterprises of their own. Numerous small industries have been set up and are now functional all over Chitral [5].

In Garam Chashma valley a raw wool processing center (washing, drying, carding, spinning, packaging) for more than 35 tons of wool annually, is adding value in the range of RS 800,000 - 120,0000, employing 20 – 30 persons seasonally and creating additional direct income to both the herdsmen and the employees. Since this project replaced partially traditional homework of women therefore women are mainly employed at the project.

Chicken-hatching using electric incubation and heating facilities are open at 3 different villages of Upper Chitral namely Booni , Morder and Mastuj.They are providing additional employment for 3-5persons and adding value to local produced corn which is used as a food for the chickens in these facilities. New and modern businesses like (photocopying, photo service, Internet and PC training) have been started in the villages as soon as they were connected to electricity.

Before the provision of electricity to the upper villages of Chitral the villages used to lack even basic facilities and were dependent on traditional methods for day to day life activities. For example traditional grinding methods were used for grinding wheat, maize and barley. All the agricultural and horticulture products were also processed traditionally. After installation of MHPs all these processes are now being carried out using electricity.

Another important small enterprise having a huge potential in Chitral is the Gems Cutting and polishin
electricity there are now 3 Gems cutting and Polishing Centers in the three different locations namely, Booni, Lotkoh and Chitral town.

6.2 <u>Social Impacts</u>

6.2.1 **Health Benefits**

Health is the most important factor which plays the key role in determining the human capital. Better health improves the efficiency and the productivity of the labor force and thus ultimately contributes the economic growth and leads to human welfare [6]. On the other hand, there is a strong relationship between poverty and the poor health. Number of Health Institutions in district Chitral are shown in the table below

Hospital	4
Dispensary	40
Rural Health Centre	4
Basic Health Units	21
Maternal and Child Health Centre	3
TB Clinic	1
Leprosy Clinic	3

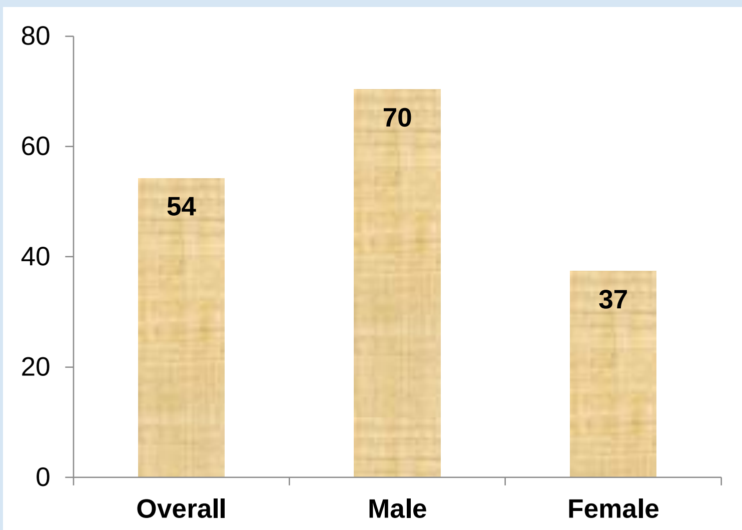
Table 6.2 Health Institutions in Chitral

Out of these Health institutions only 2 are connected to the national grid and the rest are connected to the MHPs of the villages they are located .The electrification of villages from MHPs has a very positive impact on health. It has reduced the eye and respiratory diseases resulting from traditional kerosene lamps and lanterns. The mountainous Chitral region is home of different deadly scorpions and centipedes. Proper light in night time is a prevention against them. After the electrification the health facilities have also improved significantly. The use of good lightening and sophisticated medical equipment has also contributed in the improved health facilities. Another important contribution of electricity in the health sector is the refrigeration of medicines in the BHUs and RHCs located throughout the district. It is difficult to transport various medicines to the geographically scattered areas on daily basis. The medicines are now being refrigerated on the village health centers.

6.2.2 Educational Benefits

When it comes to education Chitral is among the top districts of the province having a Literacy rate of 98% in the age group of 6-10 Years [7]. According to Pakistan Bureau of Statistics there are 600 primary schools in the district facilities if schools of Chitral are as follow. We know how important it is for an educational institution to get electrified. Unfortunately only 57% on the educational institutions in district are connected to electricity [8]. The percentage of different electrified institutions is given below in Fig 6.2.

Adult Literacy Rate - [2014-2015]



[Percentage of Schools]

	Primary	Middle	High	Total
Boundary Wall Exists	61.62	78.41	63.64	64.15
Building Availability	99.69	100.00	93.94	99.75
'Pacca' Structure of Schools	68.33	95.45	83.33	73.08
Satisfactory Building Condition	80.66	96.59	92.42	83.90
Electricity Availability	29.49	68.18	72.73	57.86
Drinking Water Availability	64.27	80.68	84.85	68.30

Figure 6.2 Electricity Availability in Different Schools

Electrification has also a very positive impact on the education of an area. It has done the same to Chitral. The improved environment to study provided by electricity has increased the study hours significantly and so have the pass rates of students. TVs and satellite dishes have increased the community's access to mass media. Now the community have broader options for entertainment.

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6.2.3 Social Capital Development

During the complete installation process of an MHP the community is part of various decision makings. The successful completeness of a project not only brings direct economic and social benefits but it helps to create a feeling of self-belief among the community members. They feel pride in contributing towards the development of their village. This raises awareness and confidence in the community.

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6.3 Environmental Benefits

6.3.1 GHG Emission Reduction

A major contribution of MHPs in Chitral is the reduction in GHG emissions from use of fuel wood and kerosene oil (the two major fuel sources used in Chitral).For their contribution in GHG emissions two organizations have won ASHDEN AWARDS for their Micro Hydel Programs in Chitral District. The Agha Khan Rural Support Program (AKRSP) and the Sarhad Rural Support Program (SRSP) won the Ashden Awards or the Green Oscar in 2004 and 2015 respectively. The Ashden Awards were established in 2001 to support the leaders in Sustainable energy to accelerate the transition to a low carbon world [10].

6.3.2 Reduction in Deforestation Rate

In rural Chitral fuel wood is the most important source of energy for cooking and heating. In all visited areas a local resource based energy mix for heating and cooking still prevails. Gas and kerosene are complementing the use of fire wood. Some studies on energy consumption reveal that per capita per annum consumption of fuel wood in Chitral is the highest in the country. Huge quantities of valuable wood are used for meeting energy shortages in the rural communities of Chitral. During winter, the fuelwood consumption increases many folds as wood is used for cooking and heating the rooms as well. Study have revealed that in Chitral about 14809.86 tons of valuable wood is used for cooking and warming houses annually. In summer season (from April to October) each person consume about 25 Kgs of fuelwood per month, while during winter (from November to March) this amount increases to 60 Kgs due to additional requirements of fuel for keeping their houses warm. This huge dependency on fuel wood is the reason that the deforestation rate in Chitral is alarmingly high. According to statistics 35% of total land in Chitral was covered by forests in the 1950 which has now reduced to just 7%.

The use of electricity for space heating has reduced the use of fuel wood is a heating source in communities connected to MHPs in Chitral. It is estimated that an electric heating stove of 1Kw capacity can save 600Kg of precious fuel wood during five winter months. As estimated in earlier section a amount of 3778 Tons of fuel wood is saved in electrified villages across Chitral.

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Chapter 7

Conclusion and Recommendations

7.1 Issues and Challenges Faced by the MHP sector in Chitral

7.1.1 Natural Hazards

The Chitral valley and some 30 subsidiary valleys are drained by the Chitral River, which has different names along separate stretches, and its tributaries. Mean rainfall is approximately between 500 mm in Chitral Town and 650 mm in Drosh (Lower Chitral), occurring mainly in the spring and winter, while the summer and autumn are dry with monthly precipitation of 10-25 mm [1]. Not the direct rainfall, but rather melt water from snow and glaciers mainly controls the hydrological regime, especially of the main rivers. Their maximum discharges occur in summer and is twelve times more than in winter. Therefore for people in Chitral water is the main natural risk factor, making water shortage a serious problem for most of them. In the harsh, dry and hot climate, water is not only of importance as drinking water, it is also the foundation of the agriculture which is still the most important employment sector [2]. Furthermore, the seasonally fluctuating water supply can episodically vary extremely, too. Some valleys that receive sufficient amounts of water in 'normal' years suffer from grave shortages in dry periods.

In contrast to the problem of droughts, large amounts of water in the alpine environment, which is characterized by high relief energy, can cause sudden gravitational mass movements, especially resulting from intense rain and snowmelt. Such processes, known as 'mountain hazards' imperil the assets and lives of the people in Chitral in the form of landslides, mudflows, avalanches and snowstorms but primary with high water and floods [3].

Both scare water in droughts and abundant water in form of floods is not suitable for the Micro Hydro Plants as well. Floods wash away MHPs almost every year in different locations across Chitral. The devastating floods of 2015 washed away 15 MHPs across Chitral. The damages were both to the power channel as well as power houses. All the MHPs were reestablished by various organizations and almost all of them are functional again. The MHPs which were damaged in the floods are given in the table below.

Chitral is also located in the earthquake zone and receives high magnitude earthquakes every now and then [4]. The land sliding caused by these earthquake also cause damages to the MHPs. In the devastating earthquake earlier in 2015 at least 2 MHPs received complete damages to the power houses and a dozen reports were of the blockage of power channel due to the landslides resulting from the earthquake.

Table 7.1 MHPs damaged by Floods

MHP Damaged	Current Status
Rabat Payen	Functional
Koghuzi MHP	Functional
Shasha MHP	Functional
Moroi MHP	Non- Functional
Khot Bala MHP	Functional
Barum Kagh	Functional
Sunich MHP	Functional
Susoom MHP	Non-Functional
Kiyar MHP	Functional
Rech Bala MHP	Non-Functional
Rech Payeen MHP	Functional
Ujnu Payeen MHP	Non-Functional
Zheture MHP	Functional

Ujnu MHP	Non-Functional

7.1.2 Cultural Complexity

Before merging as a district into NWFP, the territory of Chitral was an independent monarchical state until the late nineteenth century, when the British negotiated a forced treaty with its hereditary ruler, the Mehtar (literally owner), under which Chitral become a semi-autonomous princely state within the Indian Empire. Chitral was fully incorporated into Pakistan and NWFP in 1969 [5].

The population of Chitral is characterized by a “great cultural and linguistic complexity” and comprises a variety of ethnic groups with different languages, customs, production systems and know-hows. The majority of people belong to the Khow ethnic group and speak Khowar. Approximately 35% of the Muslim population of Chitral belong to the Islamic doctrinal tradition of Shi’a Ismaili the remaining 65% are Sunni.

These complexities influence the MHP sector as well. When Mr. Javed applied to AKRSP for the support of the construction of a micro hydel, all 45 households of his village were supporting him. They formed the Village Organization ‘Tar Shishi Koh’ and everyone participated in the construction of the project. When the generator was ready to be installed, the local mullah put pressure on the people not to accept the electricity and threatened to never visiting their houses for religious ceremonies any more. As a result, only four households completed the work and took benefit from the micro hydel. There upon parts of the other households tried, incited by the mullah, to sabotage the project. The electrified members of the community had to clean the channel during night- times, equipped with Kalashnikovs. Nevertheless, it did not take long until the channel was destroyed and only thanks to the intervention of AKRSP and the police was the situation finally settled. Now 20 households receive electricity, although according to the EMC and its three members the remaining 25 households would also have the possibility to benefit from the hydel. However, these households are not living in the darkness: They receive power from a micro hydro project built by CADP. Although financed, like AKRSP, predominantly by international donors, they consider its electricity to be halal. Yet in comparison to the AKRSP Hydel, the capacity of the

CADP one is substantial lower. As the electric wires of both micro hydels are fixed on the same poles, it was more than once that Mr.Ahmad has discovered secretly attached connections between the two wires.

7.1.3 Electricity by Alternative Providers

Around one-third of the communities that operate micro hydels are now connected to one of the electricity providers (SHYDO SHP in Reshun and WAPDA SHP in Shishi)[6] .In these villages a small minority of people have disconnected themselves from the community-owned hydel while other parts of the village use both sources parallel. These 'double-connected' households generally utilize the alternative electricity source but in cases of downtime they switch to the electricity of their micro hydel, which they normally pay regular fees for. The costs are generally higher compared to the communal electricity. Due to differences in the available electrical power as well as the billing system the price level between both community and 'alternative' electricity cannot be easily compared, but the high connection charge in particular is often a (too) high financial obstacle for many households. Apart from the high costs, the reliability of the electricity alternatives is their main disadvantage: "The transmission line [connecting Chitral Town to the national grid] remained broken throughout the winter months since the time it was commissioned in the mid-1990s" and also all villages, regardless the energy provider they were connected to, complained of a huge lack of reliability in the electricity supply.

The intervention of alternative electricity providers and the fact that both systems are used parallel gives rise to two possible conclusions: Under the prevailing conditions …

(1) Electricity alternatives are a useful supplement to community-managed micro hydels as both systems complement each other,
(2) The availability of electrical alternatives is a major threat to the sustainability of a community-managed micro hydel, as sooner or later the community will give up
Its plant.

Alternate Electricity	
Advantages	Disadvantages
High Capacity	Higher Cost
Availability	Non Reliability
No Maintenance Required	No relaxation in Case of Financial Difficulty

This availability of alternate electricity is also a problem for the MHP sector. The MHP plant in Moroi village was closed when Reshun Power Plan start operating. The community lost the interest in operating the communal MHP and eventually it was abandoned. Although the community is living in darkness since last year when Reshun MHP was completely washed away in floods and there has been no funding by the government to start the rehabilitation work on the power plant which is a source of Electricity for at least 25% of Chitral.

7.1.4 Low Efficiency of components

An important factor effecting the performance of the MHPs is the efficiency of E&M components being used in the installations. The installing organizations prefer the turbines manufactured locally within Pakistan in these MHPs because they are more cost effective than the imported ones. The efficiency of these E&M components specially the cross flow turbines is quite low as compared to the efficiency of standard cross flow turbines. This compromise in the quality of turbines affects the performance of the plant in the long run.

Another important issue which affects the performance of these plants is the use of substandard components, wires and poles, in the transmission lines of these MHPs. Normal practice is to use wooden poles for the transmission lines. This is again because they are economical than the standard poles. The use of such poles effects the efficiency of the plant on one hand and on the other hand it is of great danger to the public safety. The electric wires tied on wooden poles and even on trees in some villages always carry the threat of an electric shock.

7.1.5 Lack of Local Maintenance Service Providers

The Micro Hydro Plants are located in remote locations throughout Chitral. The maintenance as discussed earlier is a responsibility of the community itself and the installing organization provides no funds for this purpose. If community have funds or if they manage to generate fund for the repair even then they face difficulties for the repair of the damaged components of their MHP plant. They have to transport the damaged component all the way to the main Chitral city. Even in the city they can fix the issue if it is of a minor nature. For a major damage to a component they have to transport it to lower districts where they have service providers. For this reason the MHP plant remains non-functional for at least a week in case of a minor damage and for months if the damage is major.

7.1.6 Non-Qualified Operators.

Once the installation of a MHP plant is complete it is handed over to the community for operation. The installing organization provides very basic training to an operator selected by the community for the operation of the plant. There is no criteria for the selection of the operator and he is randomly selected by the community. After receiving very basic training the operator becomes responsible for all the technical operation of the MHP plant. A lot of damages to the MHP plants happen due to lack of technical expertise of the operator.

7.2 Recommendations

Hydropower stations are complex systems where all aspects must be treated in an appropriate way to achieve optimal results. Main steps are:

1. Planning
2. Implementation
3. Operation

7.2.1 Planning

The planning process starts with the formulation of realistic goals and outcomes. Realistic planning incorporates the consideration of available financial resources and time schedules. The selection of site should have been based on available development concepts or plans or if not available on defined priorities supporting the achievement of the overall project goal. The financial set-up should be manageable; contributions from various financing sources dealing with different funding set-ups and requirements should be streamlined or the time schedule should be based on the longest approval and allocation procedure. The complex technical structures require an adequate design and construction. The applied standards and quality parameters (e.g. Project lifetime, follow-up costs, reliability and availability of power supply) tem must be defined prior to design. The design of projects of such capacity requires a sound database, including reliable hydrological data, topographic surveys, geotechnical investigations, etc. Strong incorporation of communities in the planning process (and all further steps) is essential for the success. Expected economic development impacts through business development, should be based on thorough investigations and analyses (e.g. questionnaires). Funds for supporting measures should be made available within the project.

Another important factor is the efficiency of turbines being used in MHO installations throughout Ch
manufacturing. The government must ensure this prior to the start of the next phase of the MHP projects that the government is planning to install across KPK.

7.2.2 Implementation

Community based construction of civil structures puts high burden on the community and the supervising institution. The in kind contribution and the weak supervision usually ends in low construction quality and reduced project lifetime. With the introduction of cash contribution and contracting of a contractor the above negative impacts could be minimized. The approach is worth to be disseminated to and introduced in similar projects (at least for larger sizes).From the prospect of poverty alleviation the cash contribution requirement seems to put a larger share of the risk on communities. Community members have invested their years of group savings, which is unusual, and calls for very careful planning and projections of revenue.

7.2.3 Operation

O&M concepts have to be critically reviewed and possibly revised. In the past community users have been paying very low flat rate tariffs for the provision of small quantities of energy. Since the MHPs will provide considerably more energy to the users, tariffs will have to be raised to ensure sustainability. Power stations of such size are not manageable by the community. Neither management nor technical skills are available at the quality needed. The outsourcing of operation and management is therefore essential. A useful approach will be to outsource O&M functions of both Utilities, and other MHPs through a service or leasing contract, ensuring professionalization of O&M functions of installations across several villages.. With affordable, fees it is very difficult to cover operational and capital costs. Thus, the private utility risks creating deficits in the long-run. This should be considered in the concession contract. Provisions in the form of bank savings should be made for larger repairs and replacements.

Another important factor effecting the performance of MHPs are the improperly trained operators who
throughout Chitral and also for the MHPs that are to be installed in the future.

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Annex I

Conference Paper: "*The financial mechanism of Micro Hydel Program in Chitral and its impact on the sustainability of MHPs*"

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Abstract

In developing countries like Pakistan the most prominent approach to rural energy development are the programs of Rural Electrification. These programs are commonly embedded into rural development policies of a country and are often designed as a grid extension program by national power utilities. These programs do not always represent the least-cost solution for electrification due to scattered villages in rural areas. Therefore decentralized electricity generation through renewable energy (RE) is often considered as more appropriate and cost-effective. In comparison to fossil fuels, RE has significant environmental advantages and the costs of many renewable technologies have come down significantly in the last decade. Micro hydel program in Chitral, the mountainous northernmost district of Khyber Pakhtunkhwa province, is an example of decentralized rural electrification with community managed electricity generation. On one hand the success of this micro hydel program in Chitral has been widely recognized but on the other hand there are concerns about sustainability of the Micro Hydel Plants. Among many factors that influence the sustainability, one prominent factor is the current Financial Mechanism of these Micro Hydro Plants. This paper will examine the pros and cons of financial mechanism of MHPs in Chitral and its impact on the overall sustainability of the micro hydel programs.

Introduction

Pakistan at present is facing a serious and flagrant power crisis. A large section of population in Rural Areas is deprived of the energy supply whereas the population residing in Urban Localities has to face daily load shedding about 8 to 14 hours. The situation is worst in rural areas where the residents face load shedding of 12 to 18 hours [1]. Standard of living and quality of life are two factors to measure the economic development of a country and unfortunately for Pakistan energy has a direct impact on them [2]. With the existing power generation capacity it is impossible for Pakistan to provide electricity to the rural inhabitants as our energy supply is not enough to meet the present demand. Moreover, a large portion of rural areas are either too geographically scattered or remote or connecting them to the national grid is not economical[3]. So like other developing countries of the region Pakistan is trying to adopt Distributed Generation for its rural areas. Distributed Generation is a mechanism through which electricity is generated at the point of consumption from any available energy source and this generated energy is distributed locally [4].The most common sources of energy for Distributed Generation are Small Hydro Power, Wind and Solar .Fortunately Pakistan has a great potential for all these renewable resources especially Hydro Power.[5]

Due to prevailing power shortage in Pakistan and the inability of the authorities to install new power plants, the attention is being given to, Mini and Micro hydro generation in different parts of the country. The federal and provincial governments have established several institutions for this purpose such as

* Alternative Energy Development Board (AEDB)

* Pakistan Council for Renewable Technologies (PCRET)

* Energy and Power Department

* Sarhad Hydro Development Organization (SHYDO)

* Northern Areas Public Works Department

There are many hilly areas in the world where the grid will probably never reach. Chitral district of northern Pakistan, for its more parts, is one of them. The history of MHP development in Chitral goes back to 1985 when the first MHP was installed with the aim of providing low-cost electricity to remote villages of the area. Since then almost 170 Micro Hydel Projects (MHPs) ranging from 10 KW to 250 KW have been installed by different organizations using technology that is available within Pakistan. All these MHPs are being managed by the communities themselves. Due to the non-existence of coercive rules, each community establishes its own systems for operating and maintaining their micro hydel.This paper will discuss the financial mechanism of the Community managed MHPs in Chitral and will also highlight the short comings in the current financial mechanism of these MHPs.

1. Community Involvement in MHPs

The purpose of involving the community in the design and the construction and their obligation to establish their own management system is to ensure that the ownership is taken by the communities. The reliable supply of electricity during lifetime of the project is possible only when the project is well designed and constructed, appropriate tariff determined and agreed by the communities and an effective O&M system in place, which must comply with the principal interests and capacities of key stakeholders. There are three stakeholders of a MHP project

- The Beneficiary Community
- The Operator
- The Funding Organization

The reliable supply of electricity during lifetime of the project is possible only when the project is well designed and constructed, appropriate tariff determined and agreed by the communities. An effective Operation and Management model which must comply with the interests of the above mentioned stake holders is also required for efficient operation of a project.

The interest of **Community** is basically a reliable and affordable supply of electricity. The limitation of community is their ability to pay the tariff and their capacity to utilize electricity in various manners.

The performance of the ***operator*** mainly depends on how competent he is and what are the incentives given to him for his services .A precondition for sound operation of MHP is an appropriate technical training to the operator. The O&M model must ensure that the operator earns a decent living from running the project. The personal capacities skills and attitude of the operator influences the project therefore selection of the operator is crucial.[6]

The interest of ***funding organization/donor*** in a MHP project is to ensure the sustainability of the project .The communities can only ensure this through a viable Operation and Maintenance model.

Once the project is completed the beneficiary community becomes responsible for its Operation and Maintenance. The general practice for this is formulation of a Maintenance Committee.

2. Electric Management Committee

In community managed MHPs in Chitral the institution that defines and controls the governing rules is called the Electric Management Committee or the EMC. Every village has its own respective EMC and the members of EMC are selected by the community members where MHP is installed. Generally an EMC has the following important position apart from general members:

- *President:* is responsible for maintaining records of maintenance fund. He is the representative of the community in dealings with the funding organization and other matters outside the village. His signatures are necessary for using the maintenance fund.
- *Manager: He* is the one who calls meetings of the community and he leads the meetings. Collection of fee and payment of employees is coordinated by president of EMC. He is also responsible to organize communal work of

community in case of a major repair. He is also the undersigned in the use of maintenance fund.

- *Secretary: This* is another important position existing in most of the MHPs (not all). It is named treasurer in some EMCs.The duties of his member are all related to financial matters.

The monthly fees are not collected by the head of the EMC or the employees. The monthly bill is collected by the members of EMC and generally members are responsible for specific areas. The EMC held monthly meeting in which the members hand over the collected money to the manager of EMC. The manager then release salary of the employees and takes decision on punishments and sanctions.

2.1 Main Responsibilities of EMC

The members of EMC have different duties and responsibilities as discussed above. The EMC is responsible for organizing work of the employees and to generate financial resources for operation of MHP as well. The responsibilities of EMC also varies from village to village but they can be summarized as:

- *Setting tariff System*
- *Collection on monthly bills and their proper utilization*
- *Realization and decision on punishment and sanctions on free riders*
- *Organization of man power for communal works*
- *To provide skilled and non-skilled labor for construction work*
- *To select employees and their supervision*
- *Payment to employees and other financial matters*

The responsibilities of EMC members and rest of the community dis different in every village. The community member often participate in decision making process but the employee selection and the tariff is sole responsibility of the EMC and rest of the community has no say in it. The sanctions and punishments are often decided at the early stage of the project by the whole community and enforcement of these sanction is the responsibility of EMC. If a change in the rule is required the EMC holds meeting with the entire community. The EMC members are not paid for their services and they work voluntarily.

Certain number of people are employed by the EMC in every village. These members are selected by the community. The employs can be classified into four categories:

5. ***Operator***: every community employs an operator. The operator receives very basic training rom the installing authority and becomes responsible for every technical process. He supervises the machinery during operation. In some villages he is also responsible for tariff collection and even he is in charge of all financial matters in villages with no EMC.
6. ***Watchman:*** The watch is responsible for channel. He observes the channel on daily basis and removes obstacles and looks for possible breaks in the channel. He also has to clean the forebay tank. In winters he along with operator is responsible to prevent the channel from freezing. The average monthly salary of an operator is around 2000 to 3000 depending on the size of the MHP and the number of households connected to it.
7. ***Lineman:*** Some villages with large number of households employ a lineman additionally. He is responsible for providing electric connections and maintaining transmission lines.
8. ***Meter reader:*** Only villages with meters installed employs a meter reader

3. Billing Mechanisms

Apart from the characteristic of a micro hydel that it has to be maintained by means of human resources, the system furthermore requires a considerable amount of financial resources which the community members have to afford. A major part of the money is collected through electricity fees, which are mainly used for paying the wages of the staff as well as for expenditures on the regular maintenance of the machinery. While the exact utilization of the funds provided by the community will be discussed in detail in the following two sections, the fee-collection systems in the different villages can be differentiated into four different billing policies. (Fig 1)

5. Meter
6. Pure Flat Rate
7. Per Tube Light
8. Flat Rate plus fee for added tube light

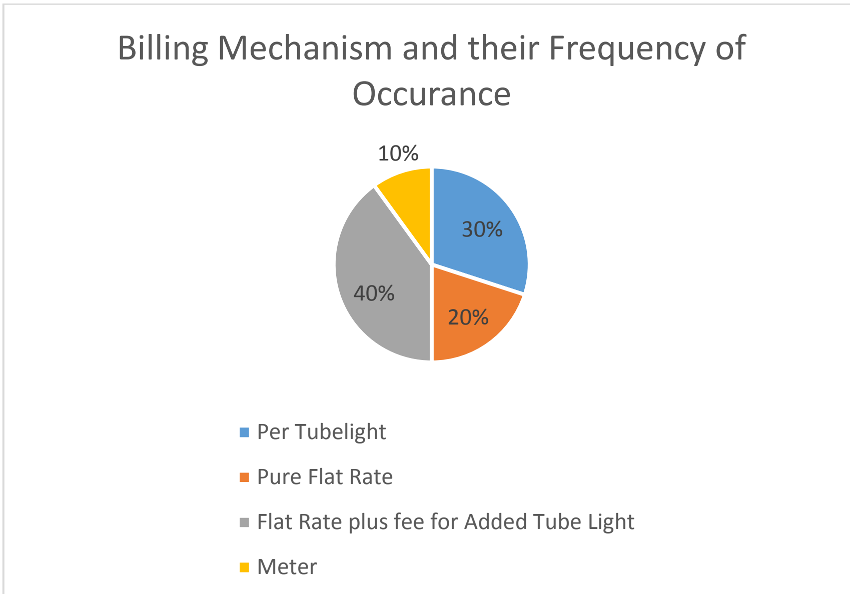

Figure 6 Billing Mechanism and Frequency of Occurrence

The most common practice in Chitral is to charge a flat rate for every household irrespective of the electricity consumed or some extra charges for added tube lights above a certain allowed number of tube lights. In 30% of the projects the fee is calculated by multiplying number of used tube lights with a certain fixed amount. The main element of billing in most of the villages is the number of tube lights used. While lightening being the most important other electrical appliances are also used in many villages. Generally there are no charges for any other electrical appliances other than TV.

The amount of flat rate and the rate of added tube light varies significantly across various MHP projects. The size of the project influences this pattern as the households connected to small project have to pay high prices to generate enough revenue to pay the staff and to generate maintenance funds.

Shops connected to an MHP are charged a special flat rate which is generally higher than the flat rate of connected households. Police stations, mosques schools and madrasas are free of charge. The flat rate per tube light varies from Rs 25/Tube light to Rs 45/ Tube light across different villages.

This kind of billing policy has different consequences:

- There is no incentive for saving energy unlike per unit billing system. The tube lights are often never switched off effecting the already scarce electricity.
- This kind of billing system is same for wealthier households having different electrical appliances like radio, TV and washing machine and for poor households having one or two tube lights and no other appliances.
- Due to low capacity of MHPs certain electrical appliances are banned in as the load on the generator has to be maintained as constant as possible. In flat rate billing policy the ability of community is questionable in implementing such kind of ban.

It becomes obvious by concluding that such kind of billing mechanism is problematic. Restriction on certain appliances cannot be imposed and a result the users of such appliances gain benefits and all other households have to bear the consequences as low electricity and as a risk to the generator. The village electricity maintenances comity or the EMC has to face difficulty in obtaining information about free riders. For example in Chinar village of Mastuj 140 households are connected to the MHP. 40 Households additionally receive electricity from the Reshun MHP installed by SHYDO. These households use electrical appliances like water heating rods, irons, electric heaters which are normally banned on the communal MHP electricity. The double electrified households cannot use both the electricity at the same time but some of them switch to the communal electricity to save the meter-measured tariff from SHYDO. The EMC in this village have come up with a solution of their own. There are three faces of the rid of the MHP and each grid electrifies different parts of the village. The operator of the MHP observes the voltage and frequency meter in the power house and can detect the misuse of electricity. In such case he switch off and on, the face that is causing the misuse, three times. This is a signal and a warning to the misuser and to the community that a misuse has been detected in their face.

Having a watchful operator is a short term solution and in the long term meters have to be installed if the MHPs are to be efficiently operated.

The monthly electricity fees is collected by the EMC in the village. In some villages the operator has to go door to door to collect the bill at the end of the month. In others the community members go to the house of the manager of EMC to handover their electricity bills. The collected funds are basically used for three purposes:

1. **Salaries**

   Each community employs at least one person for the operation of the micro hydel. As this assignment is a full-time job he receives a monthly salary. Depending on the number of employees and their wages, a village has to provide between Rs. 750 and Rs. 9,000 in funds every month.

2. **Regular Maintenance**

   The maintenance of the electro- mechanical equipment needs a considerable amount of funds for purchasing, among others, grease, belts and bearings. With considerable variations between different villages, a community has to spend on average around Rs. 540 per month, dependent among other things on the age of the equipment and quality of the construction.

3. **Emergency Maintenance**

   In the event of a breakdown of the micro hydel, financial reserves need to be available to afford the necessary repairs, especially for the electrical and mechanical equipment. In more than 20% of the villages a major breakdown of the electro-mechanical equipment happens at least once a year. Half of the break downs in the last three years were caused by a burn-through of the generator, which is responsible for almost two-thirds of all electro-mechanical breakdowns. Keeping the variations between the villages in mind, each community spends on average an additional amount of Rs. 3,500 per year on emergency maintenance

   In order to bear these three sources of expenditures, in principal each community member has to contribute financial resources in two ways:

1. Every household has to afford the monthly electricity fees, which represent the Monthly Revenues of the project
2. Apart from the monthly electricity fees, in the initial stage each household has to pay a connection charge (between Rs. 500 and 1,000) which will provide the basis for the Maintenance Fund as agreed in the Terms of Partnership (TOP).

An example of the financial model of the revenues generated from MHP is shown in Fig

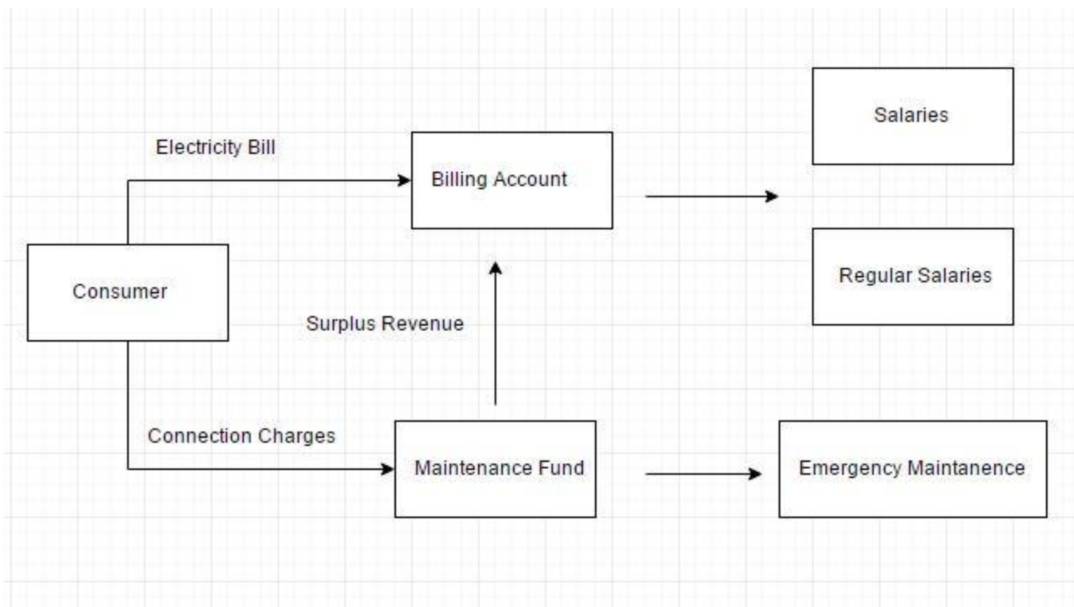

Figure 2 Financial Mechanisms of MHPs

The revenue generated from the electricity bills are put into a billing account. The salaries of the operators are paid from this billing account. After paying the salaries the remaining money is deposited into the maintenance fund and is used in case of an emergency maintenance. The financial success of a project is dependent upon the development of maintenance fund as the increase in maintenance fund will result in increase of income than expenditure.

4. Maintenance Fund

According to representative of AKRSP about 22% of the total villages that they have installed MHPs in have not established a maintenance fund although they agreed on it while signing the TOP. Majority of the villages with no maintenance fund are located in the lower part of Chitral district apart from the two MHPS managed by Kailash Community. The reason is the acceptance problem of AKRSP by Sunni and Pashtun dominated communities. In order to install an MHP in these villages' concessions were made in the ToP and establishment of a maintenance fund was dissociated.

Maintenance fund vary from village to village and without the complete analysis of the financial mechanism of each village the maintenance fun says very little about the overall financial profitability of a MHP project. The establishment and size of maintenance fund is often negotiated with the installing authority as a pre requisite for installing the project. So like other financial mechanisms it is not community made financial arrangement.

4.1 Impact of a Maintenance Fund on the financial sustainability of MHPs

It is obvious that communities having established a large Maintenance Fund have advantages. In the event of a larger repair, funding is readily available and in some isolated cases the Maintenance Fund is even enough for a future replacement of electro-mechanical parts. However, judging these projects financially more sustainable than those with no Maintenance Fund, would require the latter to evidently face more problems in financing repairs. This assumption could not be approved. The reason is that communities with no Maintenance Fund have different characteristics to the other villages. The existence of a Maintenance Fund is strongly influenced by the denominational setting. This fact also indirectly influences the size of the projects, as religious motivated tensions and reservations against AKRSP have hindered the motivation and cooperation of communities for obtaining larger project. The required money is either taken as a credit and paid back later on (see Box 9, p. 58) or collected through ad hoc levies. In that case only in very rare situations does every household pay the same amount of money; instead the people contribute according to their financial capacity. In the visited communities, these procedure have so far worked quite well, due to relatively small numbers of electrified households and there- fore relatively low organizational efforts. Apart from time lags between the occurrence of the damage and the allocation of funds, micro hydels managed by communities with no Maintenance Fund can on the basis of the collected empirical data not be considered being financially less sustainable per se than projects where such fund exits, due to their special condition.

Conclusion

This current financial model of MHPs in Chitral faces certain difficulties in different village like:

- Certain villages have not established a maintenance fund at all.
- Regular Maintenance is not met by maintenance fund in many villages, rather cash contribution is demanded from households.
- Some villages have no bank accounts at all and one person keeps all the cash money collected.
- Some villages have fixed the maintenance fund for a certain time period to enable growth due to interest.
- In some projects consumer pay the connection charges prior to the provision of electricity to them but many villages projects are still running where no connection charges were paid by the connected consumers. This kind of approach makes the generation of money difficult for maintenance purposes.
- The income generated from penalties of consumers (by the use of banned appliances) provides an additional source of income. Some EMC charge cash penalties from households not participating in communal works. This extra source of income is misused by the operator as there is no defined use of income generated this way.

The study of financial mechanisms of different villages showed that there is no single village where the accumulated funds grew (without addition of further connection charges and interest). No beneficiary community is making any profit from the installed MHP. They finance the expenses mostly through revenues and through penalties and added connection charges. They have no savings for emergency expenditure and in such case they demand cash contributions from households. There can be two explanations for the MHP projects being not financially profitable to the communities:

1. The households don't have enough financial resources to pay high fees for the electricity when demanded by the EMC of the village.
2. The community is not willing to pay high charges even if they can afford it.

In many villages the actual revenues were very less than the expected revenues. The reason for these differences is also the large amount of outstanding money. The fact that the communities face problems in collecting the existing bills questions the reliability of higher prices for the electricity

These distinctions in the financial mechanisms between different communities led to the insight that while a decrease in the Maintenance Fund indicates low financial profitability, (due to insufficient revenues or major expenditures) the reverse cannot be drawn: An increase of the Maintenance Fund is not an indicator of high Surplus Revenues. The additional fact that the quality of the financial records varies considerably between different villages makes it necessary to conduct a thorough survey of the financial mechanisms of every village.

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Annex II

Paper title: Efficiency Analysis of Locally Manufactured Cross Flow Hydro Turbines. A Case study of District Chitral Pakistan"

Submitted to Journal "Energy for Sustainable Development

1. Introduction

Hydro Power is one of the most important energy generation source throughout the world.(Okot 2013). Cost effectiveness is one reason that Small Hydro Power plants (SHPs) are used for rural electrification in regions with the necessary topography and streamflow availability in developing countries including Pakistan (Bracken et al. 2014). To diffuse decentralized rural electrification in developing countries there have been many studies which have brought out that such programs had mixed success(Paish 2003) A number of these Small Hydro Plants are installed across the Northern Pakistan by different non-government organizations including Agha Khan Rural Support Program (AKRSP) and Sarhad Rural Support Program (SRSP). The provision of electricity to these communities through MHPs has not only helped to meet lighting needs, but also, to some extent, for heating and cooking, and providing energy for small enterprise. And, with increased small enterprise, employment opportunities are created and they have also alleviated poverty in the project villages.(Kessides 2013) . The Government of Pakistan has also started investing in the water abundant Northern Pakistan. Recently the government has approved installation of more than 150 Small Hydro Plants across the Khyber Pakhtunkhwa Province (KPK). With all this focus on installation of new small hydro plants (SHPS), there is a need to know the status of already installed SHPs.

The purpose of this paper is to evaluate the efficiency of the Small Hydro Power Plants (SHPs) installed in Chitral District of northern Pakistan. Through case studies of 4 different SHP sites in Chitral, the efficiency of locally manufactured Cross Flow turbines is presented. The research outlined in this paper demonstrates that the efficiency of these plants is not meeting the international standards due to a number of reasons. The main reason of these plants to be not efficient enough is the low efficiency of the locally manufactured hydro turbines that are being used in almost all these installations.

1.1 Chitral and its geography

Chitral is the northernmost district of the Khyber Pakhtunkhwa province of Pakistan, bordering Afghanistan in the west and the Federally Administered Northern Areas of Pakistan to the east (Fig. 1). The district is divided into two sub divisions (Lower and Upper Chitral).The total area of the district is 14850 square kilometers (Pakistan bereau of Statistics 2014). It is bounded by the three famous mountain ranges, Hindukush on the northwest, Karakorum on the north-east and to the south is the Hindu Raj range (Sher et al. 2016). The Lawari pass (3,118m) in the south is the only entrance to this district. It connects the district to the rest of the country. The majority of people in Chitral are marginalized through poverty, remote location and harsh weather, where even basic amenities of life are not available (Sher et al. 2015). Overall 32% of the total population lives below poverty line. Their major source of income is from agriculture and holding livestock. Women are mainly involved in agriculture activities, while men out-migrate for seasonal labor. Only 3% of the total land is comprised of natural forest, thus the communities rely heavily on farm forestry for heating and cooking fuel purposes (Pakistan bereau of Statistics 2014). Supply of electricity to the geographically scattered population of these mountainous regions is very difficult and only 68% of the population currently has access to electricity and 50% of the electricity comes from micro hydro plants (Province 2010).In addition, the majority of the population is settled in off-grid areas, with no access to electricity facility. This situation is unlikely to change as extension of the national grid to these areas is cost prohibitive due to the remoteness of areas and the difficult terrain.

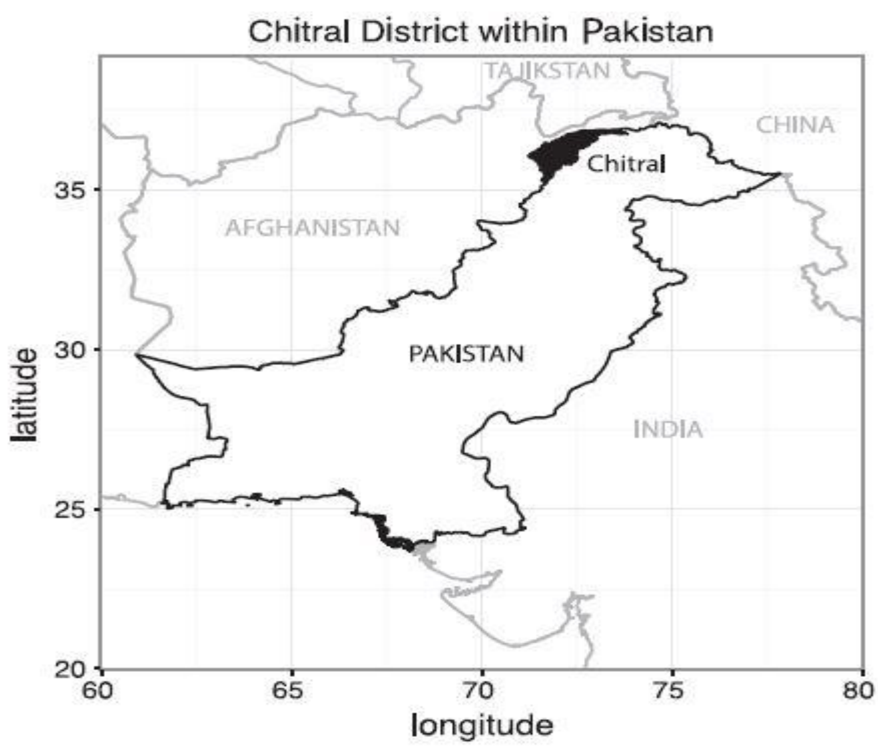


Figure 7 Location of Chitral district within Pakistan(Sher et al. 2016)

1.2 Electricity Situation in Chitral

The Water and Power Development Organization (WAPDA) supplies electric power to Chitral. This is done in two ways: First, a transmission line of 33kv connects the district to the national grid and secondly WAPDA runs a Hydro Power Station of 1 MW in Chitral Town. A second contributor to electricity in Chitral is the Sarhad Hydel Development Organization (SHYDO) that operates a 2.8 MW hydro power station, at about 60 km north of main Chitral Town, at Reshun. Several NGOS have also contributed a number of micro Hydro Plants in areas of Chitral where there is no grid electricity. It is estimated that the current demand of electricity for 52,000 households of Chitral is 35 MW, whereas the existing capacity of generating electricity is only 21 MW. Thus, there is huge gap between demand and supply of energy in the area. Demand is set to increase sharply in the near future due to increase in the population (2.5%) coupled with increased industrialization in the area. Table1 shows the current electricity situation and the major contributors of Chitral's electricity.

Table 2 Electricity Situation in Chitral

Institution	Units Installed	Capacity (MW)	Percentage Share (%)	Total Beneficiary Households	Total Population Beneficiaries
Water and Power Development Authority (WAPDA)	Singur Power House	1	17.8	15475	108325
	National Grid	2.8			
Sarhad Hydel Development Organization (SHYDO)	Reshun Power House	4.2	28.1	9100	63700
	Sheshi Power House	1.8			
Sarhad Rural Support Program (SRSP)	MHP Plants	0.45	2.1	950	6650
Agha Khan Rural Support Program(AKRSP)	MHP Plants	10.975	50.5	7016	49117
Private	MHP Plants	0.6	2.8	1350	9450
Total		21.37 MW		33891	237242

2. .... MHP Development in Chitral

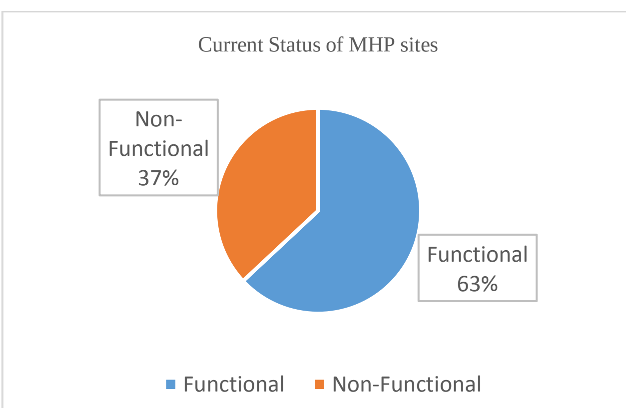
2.1 History of MHP Development

There are many hilly areas in the world where the grid will probably never reach. Chitral district of northern Pakistan, for its more parts, is one of them. The history of MHP development in Chitral goes back to 1985 when an NGO named Agha Khan Rural Support Program (AKRSP) installed its first plant in Ayun village of Chitral. The aim was to provide low-cost electricity to remote villages of the area. Since then almost 170 Micro Hydel Projects (MHPs) ranging from 10 KW to 250 KW have been installed by different organizations using technology that is available within Pakistan. More recently, AKRSP is also implementing relatively bigger projects ranging from 500 to 800 KW by using imported technology.

2.2 Current Status of MHP Plants

SHP development in Chitral dates back to 1984.Since then almost 165 SHP plants have been installed in the district. With the passage of time 64 plants have become non-functional due to various reasons. The total number of functional plants is 101 (Fig 2.2.1). The plants have different capacities ranging from 5kW-250kW. Fig 2.2.2 shows the total number of plants and their capacity ranges.

Figure 8.2.1 Chitral Base Map with existing and planned MHP Plants



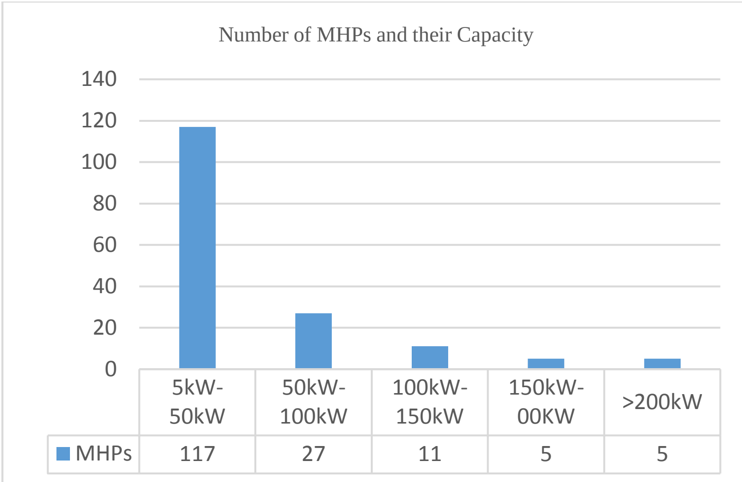


Figure 2.2.2 Total Number of MHP sites with Capacity range

3. Efficiency of Locally Manufactured Cross Flow Turbines

3.1 Cross Flow Turbine

The turbines used in the mini hydro plants installed in Chitral are cross flow turbines manufactured in Pakistan. A cross flow turbine can be best explained as an impulse turbine with partial air admission. Cross flow turbine has a drum-like rotor with a solid disk at each end and gutter-shaped "slats" joining the two disks.(Paish 2003).Cross flow turbines consists of a conical draft tube which creates a pressure below atmosphere in the turbine chamber. Air is admitted into the chamber through an air inlet valve which is adjustable and is used to control the pressure. When there are sand particles in the water entering the turbine then cross flow turbines are susceptible to wear. The runner of cross flow turbine is self-cleaning and generally the maintenance is less complex than other turbines. The shape of the blades helps the water to transfer some of its momentum on each passage before falling away with little residual energy.(Martins)

Although Cross Flow turbines are less efficient than modern day turbines but they can operate at larger water flows and lower heads. A typical Cross flow turbine is shown in Fig 3.1

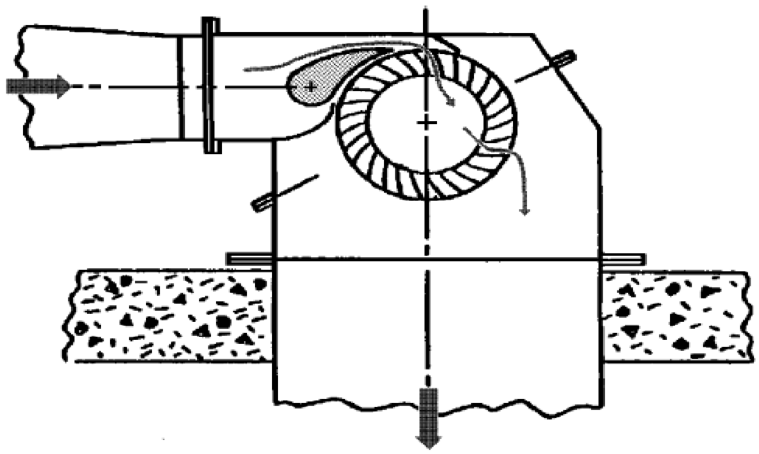


Figure 3.1 Cross Flow Turbine(Paish 2003)

3.2 Turbine efficiency

A significant factor in the comparison of different turbine types is their relative efficiencies both at their design point and at reduced flows. The performance characteristics of a cross flow turbine are similar to that of an impulse turbine. A cross flow turbine has a flat efficiency curve over a wide range of flow and head conditions. Typical efficiency curves are shown in Figure 3.2 .An important point to note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Cross flow and Francis turbines falls away more sharply if run at below half their normal flow.

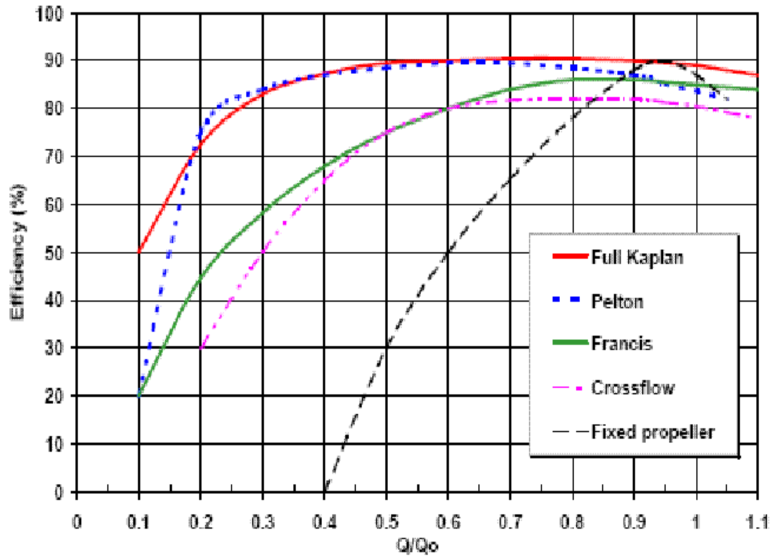


Figure 3.2 Efficiency Comparison of different turbines at reduced Flow Rates(Schleicher et al. 2014)

Methodology

The formula given below was used for calculating efficiency of cross-flow micro-hydro turbines in three different MHP plants installed in Chitral.

$$\eta = \frac{P}{\rho g Q H} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ (1.1)$$

P = mechanical power produced at the turbine shaft (Watts),
η = hydraulic efficiency of the turbine,
ρ = density of water (1000 kg/m3),
g = acceleration due to gravity (9.81 m/s2),
Q = volume flow rate passing through the turbine (m3/s),
H = effective pressure head of water across the turbine (m).

Qo =Hydro turbine maximum working flow rate

The value of ρ and g remained constant therefore the value of variable Power (P), Effective Head (H), and Flow rate (Q) needed to be evaluated. Effective head is net head at the turbine inlet, after accounting for loss head due fluid friction.

The following equipment were used for calculating flow rate, head and power.

5. Flow meter
6. Pressure transducer
7. Power meter
8. Dummy load

The dummy load used in the efficiency measurement process was a 135kVA resistive load that could be used in two alternate configurations. It could either be connected in a 50kVA configuration or a 100kVA configuration. Thus, if a load controller (ELC or MLC) was present on the site, only two readings were possible, those corresponding to the above two values of loads. This is because the load controller would automatically adjust the varying flow to suit the value of the load connected to it. In the absence of a load controller, as many readings as desired were possible. ELC was installed in some sites so there was no need to connect the dummy load. On other sites due to poor and lose connections in control panel it was difficult to connect the dummy load cable with it. Little disturbance in the panel could have damaged the whole cabling system.

Results and Discussions

Site 1 Overick

The turbine was at this site was installed in 2008.The population of this village is in excess of 2000 and 200 households are being served by this SHP site. Efficiency was calculated by varying the flow. The flow was controlled manually and mechanical load controller (MLC) was not installed at the site. Maximum efficiency of the system is 69.11% at Q/Qo = 0.86. To get maximum efficiency, the system must be operated at this condition. The variable flow rate the influenced all other parameters of the system i.e. head, power output. Based on the values of these parameters efficiency was calculated and plotted in Fig 3.2.1.

Table 3 Site Parameters Overick

Flow Rate (m^3/s)	Q/Qo	Head (m)	Measured Active Power (KW)	Efficiency, η
0.3	0.7	21.4	30.6	61.58
0.33	0.77	21.8	39.8	67.55
0.35	0.81	22.4	41.1	66.36
0.37	0.86	22.6	44.5	69.11
0.4	0.93	22.6	41.6	58.92
0.41	0.95	22.5	44.8	60.4
0.43	1	22.1	39.1	49.63

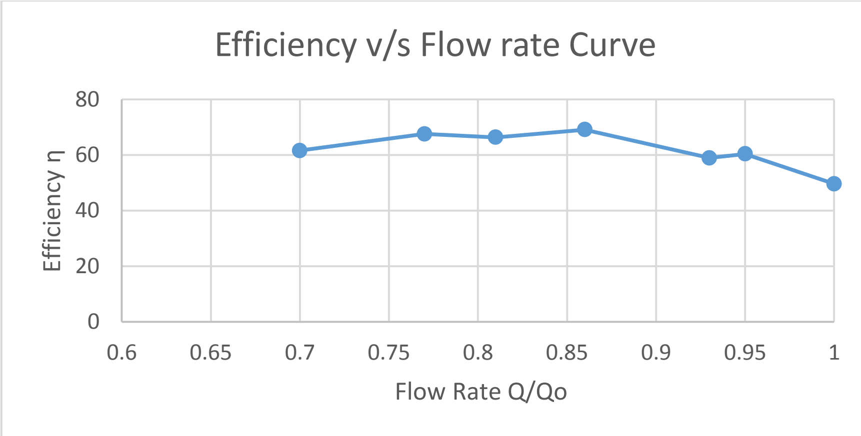


Figure 3.2.1 Efficiency Curve Overick site

Efficiency Curve Analysis:

The efficiency curve determined in the Overik site data somewhat resembles the actual efficiency curve (Fig.3-2) but there are marked deviations. The general plot of efficiency vs. normalized flow rate reaches its peak around Q/Qo=80%. The maximum efficiency is about 69%. Then the curve starts to dip as the efficiency goes on decreasing while the flow rate increases to its maximum value. Before the highest point is reached by the efficiency curve, the trend is an increase in efficiency with an increase inflow rate.The trend of the plot before and after peak value is almost similar to the general trend as shown in Fig. 3-2. The curve plotted actually shows an exploded view of one section or part of the entire curve that which is in the normalized flow rate range of 0.7-1.00. If this trend is interpolated, it will closely resemble the actual trend. The reason for the anomalies in the above graph are due to varying pressure head ratings and rapidly fluctuating power readings which has caused the curve to sway from the general trend.

Site 2 Birir

Power house is located at Nosh Bru, Birir. There are approximately one hundred & seventy five (175) houses in the area and all of them are being supplied electricity by this power house. The population of the area exceeds 1750. The type of turbine installed is Cross-Flow. The potential of hydropower generation is 75kW and the percentage of potential used is 28% approximately at the prescribed date. Average units used are 225.5. Neither ELC nor MLC was installed at the site.

Efficiency was calculated by varying the flow. The flow was controlled manually; MLC was not installed at the site. Maximum efficiency of the system is 54.42% at Q/Qo = 0.94. To get maximum efficiency, the system must be operated at this condition. System was analyzed by varying flow rate. The variable flow rate influenced all other parameters of the system i.e. Head, power output etc. Based on the values of these parameters in Table3 efficiency was calculated and plotted in Fig 3.2.2

Table 4 Site Parameters Birir

Flow Rate (m^3/s)	Q/Qo	Head (m)	Measured Active Power (kW)	Efficiency η
0.31	0.86	10.1	14.22	51.61
0.32	0.89	10.6	15.02	52.72
0.33	0.92	11.7	17.81	54.27
0.34	0.94	13.15	19.22	54.42
0.34	0.94	12.8	19.12	53.58
0.35	0.97	14.4	20.9	53.85
0.36	1	12.8	19.05	53.69

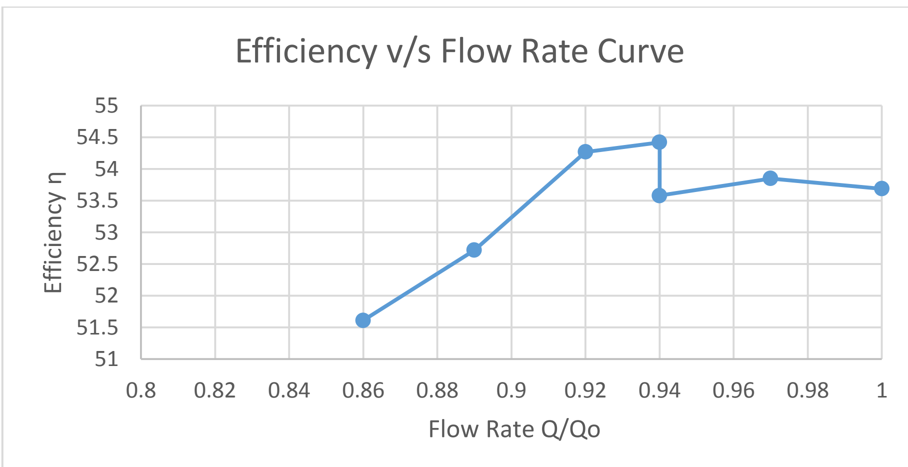


Figure 3.2.2 Efficiency Curve Birir site

Efficiency Curve Analysis

This curve is sort of a magnified view of the actual curve and it covers only the 0.86-1.0 part of the normalized flow range. The plot shows a maximum efficiency of 54.42% at Q/Qo = 94. The curve is nearly horizontal in this portion, as expected, but shows a peak value at a flow rate much larger than what is expected. The reason for this is the dubious pressure head readings in Birir, which is due to the fact that the pressure transducer gauge could not be properly fit on the turbine since there was no proper place to put it. The pressure gauge mounting on the turbine had initially been closed with a twig and hence air used to fill the channel. The old and outdated distribution box also did not aid in taking power readings and thus a large range of readings could not be taken.

Site 3 Izh

The area where the turbine site is located is called Izh, and the site itself is called Narai. There are approximately two hundred (300) houses in the area and all of them are being supplied electricity by this turbine house. There are 312 connections in which 12 are commercial and 300 are to the houses. The population of the area averages 2400 (8 person per house). The type of turbine is Cross Flow. The potential of hydropower generation is 80KW.

The system was analyzed by varying flow rates. The parameters are shown in Table4 and the based on these parameters the efficiency v/s flow rate curve is shown in Fig 3.2.3

Table 5 Site Parameters Izh

Flow Rate (m^3/s)	Q/Qo	Head (m)	Measured Active Power (kW)	Efficiency η
0.35	0.65	25.45	26.1	29.9
0.42	0.78	25.04	32.18	32.04
0.45	0.83	24.9	41.29	38.39
0.51	0.94	24.4	45.18	36.6
0.52	0.96	24.3	53.64	45.45
0.54	1	23.7	67.06	53.36

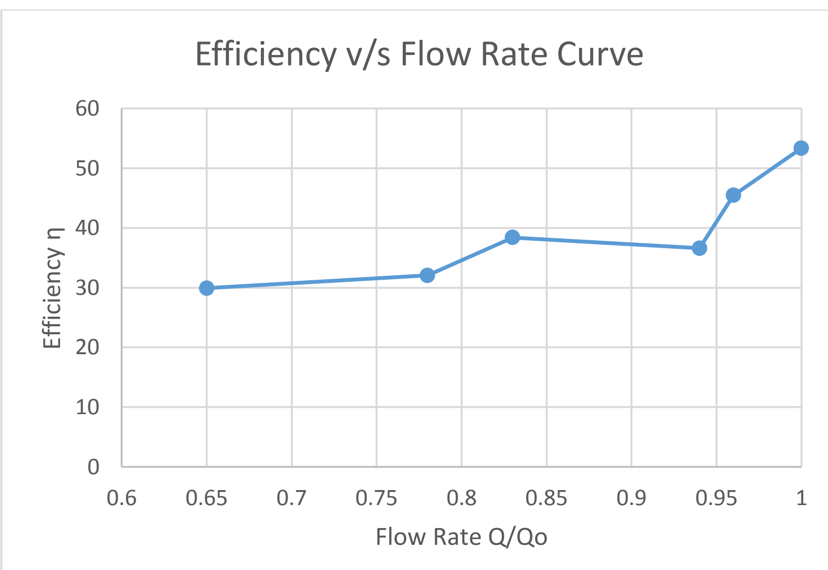


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Figure 3.2.3 Efficiency Curve Izh site

Efficiency Curve Analysis

This efficiency curve deviates largely from the original efficiency curve (Fig. 3-2) because of many shortcomings present on the turbine site. The curve shows a maximum efficiency value of 53.36% at nearly the maximum flow rate i.e., at Q/Qo = 1.0.

There was a genuine difficulty in taking power readings because of the dilapidated condition of the distribution box and the wires coming out of the generator, which themselves form a source of resistance for the flowing current and since there is a drop of potential across these wires, the measured power output readings are then affected. The generator was Chinese made and an old one. There was no place on the turbine to install the pressure transducer and hence welding was done on the spot to rectify the problem. The clearance introduced between the pressure gauge nut and the mounting lead to air being forced into the system, thus leading to errors in the values of pressure head.Even though a sufficient number of readings were taken by varying the load (ELC on the site was not operational), the error in these readings due to the above mentioned factors lead to a curve which highly strayed from the original one.

Site 4 Bilphok

The area where the turbine site is located is called Bilphok and is installed by PCRET (Pakistan Council for Renewable Energy Technologies). There were approximately two hundred & sixty (260) houses in the area and all of them were being supplied electricity by this power house. The population of the area averages 1820. The type of turbine is cross-flow. The potential of hydropower generation is 75kW and the percentage of potential used is approx. at the prescribed date. It was installed in July 2006. Based on the parameters in Table5 the efficiency curved was calculated using equation

Table 6 Bilphok Site Parameters

Flow Rate m^3/s	Q/Qo	Head (m)	Measured Active Power (kW)	Efficiency, η
0.21	0.56	19	6.02	15.22
0.22	0.61	19.2	7.66	18.64
0.23	0.64	19.4	10.88	25.4
0.26	0.72	19.33	14.12	29.7
0.28	0.78	19.4	23.42	45.87
0.36	1	18.9	28.75	42.51

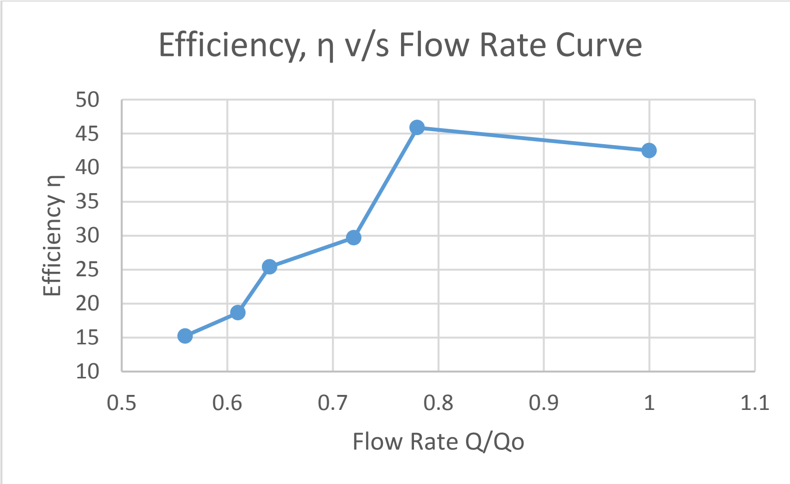

Figure 3.2.4 Efficiency Curve Bilphok site

Efficiency Curve Analysis:

The efficiency curve hugely strays from the curve normally expected for cross flow turbines (Fig3.2) in the flow rate range of 0.58-1.0. It shows the turbine maximum efficiency to be 45.87% which occurs at Q/Qo = .778. There were numerous hurdles faced at this site and hence it affected the overall results. The water flowing through the penstock in Bilphok was dirty and this hugely affected flow rate readings that were obtained using the flow meter. This explains why the maximum efficiency is obtained at such a high flow rate. The turbine and generator were worn out by repeated use and the generator in particular was of low efficiency. Hence, accurate readings could not be obtained.

Comparison of Efficiencies

The efficiency vs Q/Qo curves of all the sites is given on one graph (Fig 3.3). Overick had highest efficiency i.e., 69.1% because of its design, manufacturing installation and good maintenance. The turbine installed at Bilphok site had the smallest efficiency i.e., 45.87% because the there was a problem with the water reservoir due to which water drained away quickly. Therefore the desired head and flow rate were not available for efficient operation of the turbine.

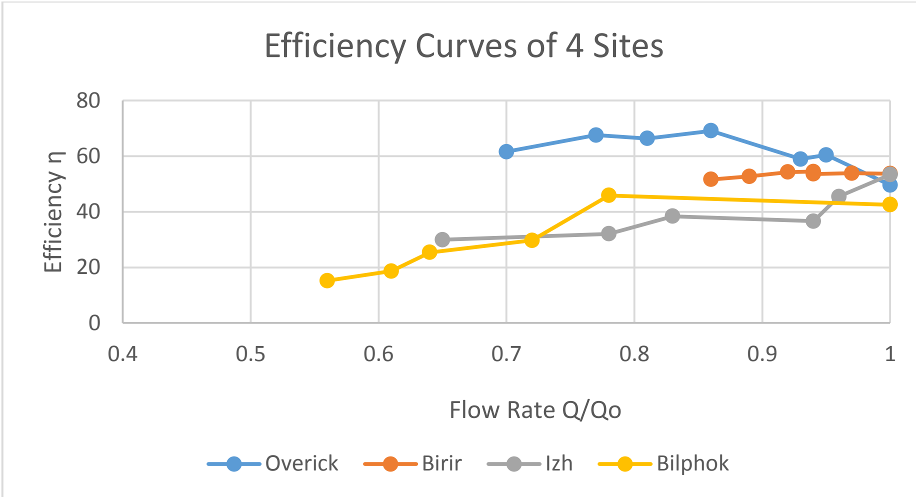

Figure 3.3 Efficiency v/s Flow Rate curves of all 4 sites

Conclusion

This is the first study of its kind to evaluate the performance of the Small Hydro Power plants installed in Chitral district of Pakistan. It was an interesting exercise to measure the efficiencies of some typical locally manufactured micro-hydro power plants which presented a clear picture of the existing situation and hence will help to assess the need for improving the design in order to increase the plant efficiency. With the passage of time the projects have been unable to meet the energy requirement demands due to increase in population and changes in usage patterns of electricity (from simply lighting to cooking, heating and supporting small enterprises). Most of the older projects have already completed their useful lives and have become in-efficient. The efficiency of the locally manufactured Cross Flow turbine used in the SHP plants is as compared to standard Cross Flow Turbines. A standard cross flow turbine has an efficiency of 83% to 85% (Kumar 2007)but the maximum efficiency of any SHP during this study was 69%.This suggests that the civil structures, electrical and mechanical equipment of these projects need up-gradation.

Acknowledgment

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