Tropical Agricultural Research Vol. 15:288-298 (2003)

An Evaluation of a Small Scale Hydropower Development Project in Sri Lanka: A Case Study in Sripadagama

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ABSTRACT. *Sri Lanka has utilized all the possible large-scale hydropower sources. Among the other renewable and least cost sources, there is a potential to establish small hydropower projects in the up country of Sri Lanka. According to previous studies, it is possible to generate over 500MW capacity of energy from the streams in the up country. However, due to adverse potential environmental impacts of such small hydropower projects, the decisions to establish small hydropower projects should be based on sound hydrologic and economic analyses. This study investigates the potential for establishing a small hydropower project in Sripadagama on the Kalu Ganga in the Sabaragamuwa Province in Sri Lanka. A detailed hydrologic investigation was carried out in the Sripadagama catchment, using the linear-non-linear tank concept. This hydrologic model was used to predict the stream flow at the project site. The costs included in the study were, physical cost, risk of dam failure and externalities, particularly deforestation and degradation of biomass. The benefit ('unit value') transfer method was used to incorporate environmental costs in the project. The main benefit considered in the project was hydropower generation. After evaluation of the technical feasibility, an extended cost-benefit analysis was carried out to investigate the economic viability of the project. Software was developed to do both hydrological and economic analysis with time efficiently. The accuracy of predicting the stream flow at the dam site is 89.3%. The extended benefit cost (EBC) analysis shows a favorable result (BCR 2.2) according to the variables considered in this project. However, further research is needed to capture more realistic results.*

INTRODUCTION

Sri Lanka is very rich in terms of water resources and has a proud history over the last 2500 years. Still 55% of the people in the country have an agro-based life style and economy, especially in North Central and Eastern parts of the country. Many ancient irrigation tanks and canal networks were established in those areas and people still utilize those resources towards their sustainable development. After 1977, the government of Sri Lanka decided to switch to the open economic system and entire society changed dramatically. As a result many infrastructure facilities had to be developed quickly to suit the people's needs and to attract foreign investors. Power, highways, telecommunication, health are a few which are at the top of the list.

Low cost energy is a requisite for almost all the developing countries in the world including Sri Lanka. Adequate power has been an important issue over the last 25 years. Fortunately there were enough water resources in the country to address the problem at the initial stage. Ceylon Electricity Board (CEB) is the sole power supplier

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to the nation and it has 1117 MW of hydro, 563 MW of gas and thermal and 3MW of wind power capacity.

The total capacity is 1703.45 MW and according to the CEB's estimation the power demand is increasing at a rate of 8 % annually (ITDG, 2000). Most of the large-scale water resources have already been used. Therefore this is the best time to look at other alternative energy sources. Solar energy, thermal energy and small-scale hydropower are such possible energy sources that can be used to address the problem (Munasinhe M., 1980). Out of them, solar energy can be utilized specially for rural areas where there is a low consumption of energy compared to the urban and industrial sector. The other source of energy is small-scale hydropower and more often called mini hydro. The central highlands in the country receives high rainfall during the first inter monsoon (March-April), South West monsoon (May- September), second inter monsoon (October-November) and relatively less rainfall during the North East monsoon (December -February). The average annual rainfall in the central highlands varies from 2500 to 6000 mm. Perennial streams and sudden elevation drops in the river valleys create excellent conditions for small-scale hydropower generation. The tributaries of major rivers are capable of developing more than 500MW capacity of hydro energy.

After 1996, once CEB decided to purchase power from the private sector, the construction of small-scale hydropower plants became popular. Power generated by small hydro plants is purchased by CEB through a power purchasing agreement signed between CEB and the power developer. This system has worked satisfactorily over the last few years. The initial step is a feasibility report that should be submitted to CEB to obtain a Letter of Intent (LOI) from CEB indicating willingness to purchase power produced by the project. Apart from the approval from CEB, it is necessary to obtain the approval from local government authorities such as the Pradeshiya Sabha and the Divisional Secretariat. Finally, the approval from the Central Environmental Authority is a must for the environmental clearance of the project.

Power demand changes temporally and spatially. Out of them, temporal changes are the most critical for the supplier. Power supply should be reliable for consumers so that their demand is satisfied at every point in the time scale. For daily demand, generally it is possible to identify two peaks, in the morning and in the late afternoon. Satisfying the base load is normally done with hydropower so that the cost is minimized. However, the hydro capacity might not be enough to satisfy the peak demands. Then the thermal and gas power plants should be switched on even though they are very costly. The situation can change in dry periods where most of the storage reservoirs face a water shortage. Then the base load is supplied by thermal power and the peaks can be achieved by hydro power. Ultimately, the cost of power is increased dramatically.

If the peak demands can be achieved by hydro itself, the cost can be decreased considerably. That should be the main aim of developing low cost energy sources such as mini hydro and solar power. Studies on small hydropower projects are scarce in Sri Lanka. A few small hydropower projects started recently in Aranayake and Huluganga are operating satisfactorily. There are few under construction as well. However, the feasibility studies of these were carried out with regression models that had not given adequate weight to environment losses. In this context, the major objective of this study is to investigate the feasibility of establishing a small hydropower project in

Sripadagama in Kalu Ganga. The specific objective of the study is to develop a hydrological model that incorporates the environmental component.

METHODOLOGY

Project area

The proposed project is in Ratnapura district, approximately 120 km from Colombo. The weir site is located on Maskelioya, which is a tributary of Kalu Ganga. The weir is located at 80.45 E Longitude and 6.75 N Latitude. The catchment area is 19.1 km^2. The nearest rainfall gauging station is at Hapugastenna, which receives average annual rainfall of around 4900 mm.

The water shed receives high rainfall in the South West monsoon period. Apart from that, the first inter monsoon and second inter monsoon periods also give considerable amount of rainfall to the project area. The project area receives less amount of rainfall when the North East monsoon is too weak. For the complete designing of the project, several alternative sights were investigated. The most favorable location was selected for the weir by considering the elevation. A detail geological survey is not critically important for small-scale hydropower projects. However, geological investigation was performed to confirm the stability of the weir. Data regarding stream flow, rainfall *etc.*, were collected for the hydrological analysis. Apart from that, structural and electrical engineering aspects also were considered. In this study the hydrological component was analyzed in depth, as this part is the most critical factor that determines the feasibility of the entire project. To determine the economic viability of the project, a benefit transfer approach was used to incorporate the forest cover loss due to the project. The benefit transfer method is useful to transfer the environmental valuations done in similar sites to the project site. The design lifetime of the project was considered to be 30 years.

Hydrological study

Hydrological study is the key for the design and utmost precision was given for the hydrological analysis. Unfortunately, there is no analytical method for predicting hydrological parameters exactly due to the stochastic nature in climatic data. Hydrological modeling is a reasonably accurate approach to overcome the problem. The accuracy of the output is determined by the complexity of the model. For this particular purpose, predicting the runoff at the dam site was done with available rainfall data for 25 years. Therefore it was possible to go for gauged models rather than hanging on un-gauged type models. The hydrological model proposed for the analysis is described below.

Linear tank concept

This concept is widely used for stream flow prediction in different parts of the world, especially for hydropower development. The concept has a great deal of flexibility to make appropriate changes according to the location. Here a conceptual tank model is introduced to simulate the entire catchment as a single unit. The catchment is considered as two different layers named as upper zone and lower zone. The top layer is named as surface storage and the second layer is known as ground water storage. Then it becomes more realistic. Two different tanks are assigned to represent each layer. The top tank (surface storage) receives the rainfall as an input and evapotranspiration, surface runoff, lateral flow and percolation to the ground water storage as outputs. The bottom tank (Ground water storage) receives the flow from the surface storage as an input and base flow and deep percolation as outputs. The system operates continuously with the given rainfall.

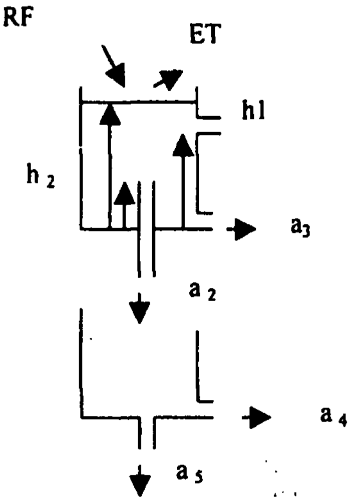

Fig. 1. Two-tank model.

For linear tanks,

$$S \alpha q$$

Applying above concept to the model,

q_1	=	a_1*[s-h_1]	if s>h_1
	=	0	o.w
q_2	=	a_2*[s-h_2]	if s>h_2
	=	0	o.w
q_3	=	a_3*[s]	if s>0
	=	0	o.w
q_4	=	a_4*[u]	if u>0
	=	0	o.w
q_5	=	a_5*[u]	if u>0
$Q_{(generated)}$	=	q_1 +	q_3 + q_4

Considering the continuity we can obtain the following equations,

For top tank,

$$s_{(t)} - s_{(t-1)} = RF_{(t)} - ET_{(t)} - \{q_{1(t)} + q_{2(t)} + q_{3(t)}\}$$

For bottom tank

$$u_{(t)} - u_{(t-1)} = q_{2(t)} - (q_{4(t)} + q_{5(t)})$$

Here, the optimum values for a_1, a_2, a_3, a_4, a_5, h1, h_2, $s_{(0)}$, $u_{(o)}$, $t_{(0)}$ are found by using a trial and error method. The optimum values were found by observing the coefficient of efficiency (E), which is given by;

$$E = [1 - Sr/Sq]$$

Where,

$$S_r = \mathrm{Sum}\{[Q_{obs(i)} - Q_{cal(i)}]2\}$$
$$S_q = \mathrm{Sum}\{[Q_{obs(i)} - Q^*]\}2$$
$$Q^* = \text{mean of observed stream flow}$$

Data series from 1955-1970 was considered to find out optimum parameter values of the model (efficiency 89.3%) and 1971-1980 data were taken for verifying the model (efficiency 80%). The following points were taken into account during optimization of parameters:

1. Evapo-transpiration was taken as a constant throughout the period.
2. The optimum values were decided by the coefficient of efficiency and the values obtained were confirmed by the flow regime.
3. For analysis, monthly data were considered for all gauging stations and that is an important factor to be mentioned here.

The watershed above Malwala was taken to find model parameters. Monthly average data of six rainfall gauging stations at Carney estate, Hapugastenna, Malwala, Lellopitiya, Massena, Pelmadulla were averaged by Thiessen Polygon method and stream flow measured at Malwala were used for model calibration.

Environmental feasibility

Environmental feasibility of development projects is important to control or minimize environmental pollution. Sri Lanka has experience in water related development projects, especially after independence in 1948. Most of the projects do not give expected outputs, including the Mahaweli Development Project. Therefore, in this project, loss of forest cover and its total economic value were considered.

Benefit transfer method

Due to time and budget constraint, environmental values were obtained from an existing study and the benefit transfer method was used. The benefit transfer method offers the opportunity to use benefits estimated for one site to be used for other similar sites. Some economists are not in favor of using the benefit transfer method because its validity and reliability are subject to existing studies. As necessary assumption for benefit transfer method, *Sripadagama* has a similar environment as *Hantana* and the effect on population was found to be the same. Thus the transferred value required some adjustment for socio-economic factors such as level of income. Thus the *Hantana* rain forest's total economic value estimated by Kotagama (1998) was used as base value. Adjustment to this transferred environmental value was done for price and risk to assess the viability of the proposed project at the *Sripadagama*. The other benefit transfer method is 'functional transfer', which is more accurate than the unit value transfer in that the whole function is transferred. However, the low coefficients will cause inefficiency and estimation can lead to uncertainty. In such case, the unit value transfer method would be more appropriate.

Along with this, conservation and aforestation in the project sites, risk of dam failure *etc.*, were calculated with the other construction, installation, operation and maintenance costs of the project. The machinery was considered to be replaced after 15 years. The benefit from the project was the generation of hydropower from the project. Resettlement cost, land acquisition cost and other externalities such as social and cultural losses, water logging and salinity problems were not considered as there were no such issues coming under this project.

This small-scale hydropower project only generates 7.9 GW h energy. Therefore no massive dams will be constructed across the stream. The intake structure is a simple weir with the height of 2.5 m. The penstock line from the intake to the power station is 1.5 km in length. The river stretch can be affected locally in between the weir and the power plant. The aquatic nature in this stretch will not be in danger during the dry period, due to only a minimum of water being released and this was considered in the design. In other words, releasing adequate amount of water to the down stream without taking the total amount of water for power generation was taken to address this problem. Theoretically it is possible to increase the performance of the plant by having weekly storage capacity. Then the plant can be operated at a higher level than without storage. However, in this project this aspect has not been utilized yet due to a siltation problem. Uprooting of trees will be done along the penstock trace only. The loss of forest is not more than 10 ha. Conversion factors were used to find the more realistic economic value of the externalities. Other than that there will be no massive structures constructed. The negative effects can be kept at a minimum by introducing a close monitoring system. The infrastructure development of the area is also possible up to a certain extent. Under this, electricity, telecommunication, and roads will be developed in the project area. Other than that, the employment opportunities created during construction and operation is also a considerable factor. The field is equally opened for civil and electrical engineering disciplines.

These types of projects have higher initial cost and less Operational and Management cost. After construction of the plant, the revenue depends mainly on the stream flow. To evaluate the economic feasibility extended benefit cost analysis was carried out. The discount factors (i%) for the financial and economic analysis were 15% and 6%, respectively. The financial interest was based on current commercial lending rates by banks. The economic interest rate is the rate recommended by the Department of National Planning. The cost and returns were shadow priced using conversion factors recommended by the Department of National Planing, Sri Lanka. Benefit cost ratio (B/C), Net Present Value (NPV) and Internal Rate of Return (IRR) were used in deciding the overall feasibility of the project (Gitinger J.P, 1990). The sensitivity analysis was carried out at social discount rate of 6% for project cost increased by 10% and the flow reduction by 10% and 25%.

$$\text{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t}$$

$$\text{IRR gives when, } \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$$

$$\text{B/C} = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} / \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$$

where:
B_t= Benefit at time t, C_t = Cost at time t, i = Discount rate, n = Number of years

However, there are some errors included in cost- benefit analysis (Panayotou, 1996) such as difficulty of quantifying all the costs and benefits and selection of the best discount factor.

RESULTS AND DISCUSSION

The optimum parameter values are given in table 1. The coefficient related to surface runoff (a_1) is equal to 0.6. The value of a_1 varies from 0.5-0.7 in most cases in wet zone watersheds. However, the obtained parameter values do not give global optimization. Therefore it is not recommended to calculate flow components separately. However the model gives 89% accuracy in predicting the total stream flow and that accuracy is reasonable for the purpose. The model parameters can be used for similar watersheds where climatic data are not available.

Design parameters

Flow duration curve (FDC)

Flow duration curve is the most important derivation from the hydrological model as it is the decision making tool of the entire project. Selection of the design flow from FDC should be done sensibly by considering almost all the factors. In some cases minimum amount of flow should be released for downstream uses. In such cases it is not possible to consider the plant as an isolated unit from the environment. Dependable flow of the stream can be utilized to develop power throughout the period. However, selection of the base flow as the design flow is not economical; as the dependable flow is very low in most of the streams that are used for mini hydro plants. Generally a quantitative measure known as plant factor, which is defined as follows, is used to decide the design flow from the flow duration curve.

Table 1. Optimum coefficient values in Sripadagama small scale Hydropower plant.

Parameter	Value
a_1 (flow coefficient corresponding to the surface runoff)	0.600
a_2 (flow coefficient – the flow from upper zone to the lower zone)	0.010
a_3 (flow coefficient – the lateral flow from the upper zone)	0.002
a_4 (flow coefficient – the lateral flow from lower zone)	0.005
a_5 (flow coefficient corresponding to the deep percolation)	0.005
h_1 /(m) (moisture depth at the surface runoff occurs)	0.500
h_2 /(m) (moisture depth at the flow from upper - to the lower zone)	0.280
S /(m) (storage of the upper zone)	0.600
U /(m) (storage of the lower zone)	1.500

Plant factor = (Annual energy produced) / (max. possible energy production)

Plant factor in between 0.6 and 0.7 is considered as acceptable and that can be used as a guide for design. Optimizing the project parameters can prove this. Anyway, there is a risk of selecting less than 40% flow as design flow due to the uncertainty of flow in the stream.

The static head available for the project is 79 m. After the head losses in the penstock line, the net head is around 70 m. The design flow and net available head are the main design parameters of the project. The cost of installing 1 kW is around Rs.100, 000.00 but the figure varies with the selection of turbine type.

Once the design flow (Q) is calculated, the energy is calculated from the following equation.

$$\text{Energy (E)} = \rho g Q h * \text{plant efficiency}$$

The plant efficiency is around 0.85. The current purchasing price of energy by CEB is Rs.5.60 per kWh. Then the revenue can be calculated directly and the rest of the analysis will deal with the costs and benefit

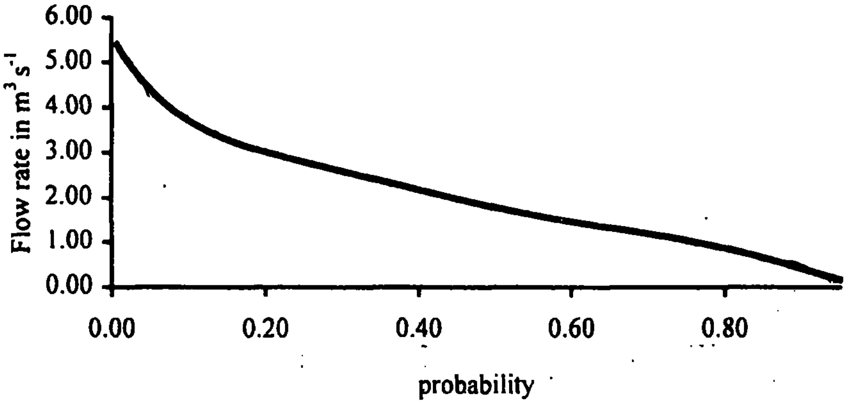

Fig. 2. Flow Duration Curve for Sripadagama small scale hydropower plant.

Table 2. Energy production in Sripadagama small scale hydropower plant.

Month	Jan	Feb	Mar	Apr	May	Jun
Energy GWh	.39	.34	.28	.47	.79	.79
Month	Jul	Aug	Sep	Oct	Nov	Dec
Energy GWh	.87	.78	.82	.88	.84	.62

Table 3. Project parameters in Sripadagama small hydropower plant.

Parameter	Value
Plant Capacity	1300kW
Annual Average Energy	7.9GWh
Net Head	70m
Design Flow	2.2m3/s
Project Cost	Rs.180 Million
Plant Factor	68%

Economic analysis

The benefits and cost of the project were transferred into economic values by using conversion factors. In this calculation, it was assumed that the rate of purchasing increases by 5% annually whereas the O and M cost increases by 6%. After 15 years time Rs. 20 million is provided for replacing major machinery parts. The environmental losses have been taken as an initial cost and reasonable cost was allocated for maintaining the surrounding environment during the lifetime of the project. This includes soil erosion control measures, slope maintenance, desilting and maintaining the scenic beauty of the surrounding environment. The construction cost was estimated as Rs. 180.0 million.

Table 4 shows that at 6% discount rate the BCR = 5.9, IRR = 29% and NPV= Rs. 882.7. This indicates the economic viability of the project. The cost of deforestation and other environmental losses was taken as Rs. 1.0 million. This value was much higher than the real estimated value for forest loss. Appendix 1 presents the financial analysis calculated at 15% interest rate with market prices. The values generated from comparison between physical cost and the costs of externalities are presented in the appendix. The economic analysis shows the long-term environmental losses are overcome by benefits of the project. Sensitivity analysis done at 6% interest rater considering, cost increase and flow reduction, did not change the above conclusion. Sensitivity analysis shows that the project was relatively leas sensitive to changes in cost while being more sensitive to flow reduction.

Table 4. Results of economic analysis and sensitivity analysis of the small hydropower project at Sripadagama.

Discount factor	NPV Rs. Mill.	IRR	B/C
06%	882.7	29	5.9
Sensitive analysis for cost increase and flow reduction at 6% discount rate			
Project cost increase by 10%	863.9	27	5.3
Flow reduction by 10%	773.4	26	5.3
Flow reduction by 25%	609.5	23	4.4
10% increase cost & 25% decrease flow	590.7	21	4.0

CONCLUSIONS AND RECOMMENDATIONS

Both hydrological analysis and economic analysis show the viability of the Sripadagama small-scale hydropower project that generates 7.9kWh/year. Even though small-scale hydropower is one of the best solutions to meet the increasing demand, such projects should be properly designed. A detail investigation on hydrology as well as the economic concepts is equally important. It is better to use daily climatic data instead of monthly data.

The environmental considerations are extremely important and therefore further closer investigations are needed on environmental factors. However, long-term environmental and social effects are in both positive and negative directions. The benefits of the project such as electricity, employment opportunities and infrastructure development of the area overcome most of the negative effects of the projects.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to the anonymous reviewers for their valuable comments and critical remarks on the manuscript. The authors are also grateful to Eng. G.R.A.S. Gunatillake for invaluable assistance given for the hydrologic investigation of this study.

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APPENDIX

Financial analysis of the small hydropower project at Sripadagama.

	Rs. Million						
Year No	Capital Cost	Env. Cost	Operation & Mgt.	Sale Value	Annual Revenue	Cash Flow	Present Value (15%)
0	130	1	0	0	0	-131	-131.00
1			0.75	44.15	43.4	43.4	37.74
2			0.8	46.36	45.57	45.57	34.45
3			0.84	48.68	47.84	47.84	31.45
4			0.89	51.11	50.22	50.22	28.71
5			0.95	53.67	52.72	52.72	26.21
6			1	56.35	55.35	55.35	23.93
7			1.06	59.17	58.11	58.11	21.84
8			1.13	62.13	61.00	61.00	19.94
9			1.2	65.23	64.04	64.04	18.20
10			1.27	68.5	67.23	67.23	16.62
11			1.34	71.92	70.58	70.58	15.17
12			1.42	75.52	74.09	74.09	13.85
13			1.51	79.29	77.78	77.78	12.64
14			1.6	83.26	81.66	81.66	11.54
15			1.7	87.42	85.72	85.72	10.54
16	20		1.8	91.79	89.99	69.99	7.48
17			1.91	96.38	94.47	94.47	8.78
18			2.02	101.2	99.18	99.18	8.01
19			2.14	106.26	104.12	104.1	7.32
20			2.27	111.57	109.3	109.3	6.68
21			2.41	117.15	114.75	114.8	6.10
22			2.55	123.01	120.46	120.5	5.57
23			2.7	129.16	126.46	126.5	5.08
24			2.86	135.62	132.75	132.8	4.64
25			3.04	142.4	139.36	139.4	4.23
26			3.22	149.52	146.3	146.3	3.86
27			3.41	156.99	153.58	153.6	3.53
28			3.62	164.84	161.23	161.2	3.22
29			3.83	173.08	169.25	169.4	2.94
30			4.06	181.74	177.68	177.7	2.68
	NPV= Rs.222 million			BCR=2.2		IRR=	29%