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Case Report

Performance Evaluation of Hydropower plants of Nepal using Multi Criteria Decision Analysis: Review Study

Dak Bahadur Khadka*

Purwanchal Campus, Dharan, Institute of Engineering, Tribhuwan University, Nepal.

ABSTRACT

Nepal having huge hydro power potential of 83000 MW is using only 1% energy from hydropower (very clean, sustainable and renewable energy resources) .Despite huge potential are untapped and importing power to meet the demand. The gross installed capacity of the country is 900 MW developed within over 100 year's period from 1911 to till this date and.653 MW is importing from India. Water resources are only one reliable source to generate income from hydropower development for Nepal and can significantly increase the national economy. But unfortunate the nation is depending on the other countries to import the energy. To reduce the economic loss in energy import, hydropower development must be given first priority and the existing plants should be in well operation conditions. To improve the performance of the plant regular performance evaluation should be carried out. With the age of plants the deterioration causes decrease in plant efficiency. To rectify the condition timely evaluation is must. Such that the evaluation enables the decision maker to take action for the improvement of the plants in effective way. This evaluation study is carried out for both existing large and medium plants on the basis of Multi Criteria Decision Analysis (MCDA) which includes energy production profile, self-sufficiency, plant factor, O/M cost, energy generation cost and staff level as evaluation criteria. From the study the energy production cost found high in case of large power plants but they are operation in better conditions than medium power plants. Medium power plants found to be repaired as soon possible.

Key words: Hydropower; Performance evaluation; Multicriteria decision analysis

INTRODUCTION

Nepal is a mountainous country having plain region to highest peak Mt. Everest and its altitude ranges from 60 m to 8848.86m (new measured value by Nepal government) and entire area 147181 square km. It has four large river systems as Sapta koshi, Gandaki, Karnali and Mahakali [1]. Since the rivers are originated from high Himalayan range they are perennial in nature and southern rivers are originated from Mahavarat range are also perennial. The rivers are flowing from steep gradient so the power potential is very high and considered as a major nation's economic source from hydropower development [2]. The total potential is 83000 MW out of which only around 1% is used for hydropower generation [3]. The power demand is increasing by 10% each year and the present peak demand is around1500MW [4]. The total generation capacity is about 900 MW which includes large and medium power plants. To meet the demand 650MW is purchasing from neighboring country India due to which a substantial amount of money is spending for power purchase which is huge economic loss for the nation [5]. Importing of such huge amount of energy nation has declared load shedding free country however the force shedding is to be done as the most of power plant are peaking run off river type .The impacts of environment and natural hazards are equally severe due to geographical and unplanned development works in hilly area specially in road construction projects [6]. The landslides and flood are vulnerable to hydropower operation and also hazardous to the physical and human life loss during monsoon season every year [7]. The investment on hydropower development is so huge owing to which poor country like Nepal is unable to use water resources and lagging behind to rise up its economic growth [8]. Despite the nation is rich in power potential is unable to tap the water resources for hydropower development. However the nation has new policy to invest from foreign investor in hydropower development project [9]. To meet the power demand it is most important to maintain the existing power plant in well operation condition to the country like Nepal that totally depends on hydropower for energy and has no other sustainable energy source like solar, nuclear and petroleum [10]. So this study is aimed to review the conditions of the large and medium power plants of Nepal electricity authority (NEA, Nepal) so that a good evaluation could be done to achieve the well information that can be useful to take effective decision on policy, planning and implementation level in hydropower development projects .

***Correspondence to:** Purwanchal Campus Dharan, Institute of Engineering, Tribhuwan University, Nepal, Tel: 9779842543974; E-mail: dakkhadka@ioepc.edu.np

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AIM OF THE STUDY

The main aim of the study is to evaluate the performance of the large and medium plants so that improvement works can be carried out to enhance and upgrade the efficiency of the plants and the reliability of the power generation can be achieved.

RESEARCH METHODOLOGY

To achieve the aims targeted, the study is based on both qualitative and quantitative information. The study is based on secondary data field. Analysis was carried out on the plant as a whole from its intake section to generator section. Empirical data were obtained from plant records for a period between 2002 to 2017, prepared by the power plant and maintained by Operation and Maintenance Department of the power plant (Nepal Electricity Authority).

Evaluation Criteria

The study covers the main issues: energy generation profile and its sustainability, efficiency, economic, self-sufficiency, plant factor, employment level, unit cost of operation, maintenance and generation as Multi Criteria Decision Analysis (MCDA). These parameter are most useful for performance evaluation of hydropower plants [11].

RIVER SYSTEMS AND HYDRO POTENTIAL OF NEPAL

The main river systems of Nepal are: (a) Koshi River system, (b) Gandak (Narayani) River system, and(c) Karnali and (d)Mahakali River system which are shown in Figure 1(a,b) [12].

The Koshi River system is the largest and originated from the top four Himalayan peaks (Mt. Everest-8,850 m, Mt. Jannu-7,710 m, Mt. Makalu-8,462 m and Mt. Cho Oyu-8,201 m). This is also called Sapta Koshi for its seven Himalayan tributaries in eastern Nepal: Indrawati, Sun Koshi, Tama Koshi, Dudh Koshi, Liku, Arun, and Tamor. The Arun is origined at Tibet 150 km far from Nepal's northern border. A tributary of the Sun Koshi, Bhote Koshi also originated in Tibet.The total hydro potential of this river basin is 22350 MW.

The Gandaki (Narayani) river system is originated from Mt. Annapurna (8,091 m) and Mt. Manashu (8,163 m).The Gandaki/ Narayani river consists seven Himalayan tributaries in the middle of Nepal:Daraudi, Seti Gandaki, Madi, Kali,Marsyandi, Budhi, and Trisuli. This is why the Gandaki/Narayani river system also called Sapta Gandaki.

The river Kali Gandaki rises from Tibetan Plateau and flows through the Mustang, then between the 8,000 m Dhaulagiri and Annapurna ranges in the world's deepest valley. The Trisuli rises north of the international border inside Tibet. After the seven upper tributaries join, the river becomes the Narayani inside Nepal and is joined by the (East) Rapti from Chitawan Valley. After crossing into India, its name has been changed to Gandaki and finally joins the Ganges River system. The total hydro potential of this river basin is 20650 MW.

The Karnali originated from two mountain peaks: Api (7,132 m) and Kanjiroba (6,883 m). The Karnali drains western Nepal, with the Bheri and Seti as major tributaries. The upper Bheri drains Dolpa, a remote valley beyond the Dhaulagiri Himalaya. The upper Karnali rises inside Tibet near Lake Manasarovar and Mount Kailash. The area around these features is the hydrographic nexus of South Asia since it holds the sources of the Indus and its major tributary the Sutlej, the Karnali-a Ganges tributary and the Yarlung Tsangpo/Brahmaputra. The total power potential of this basin is 36180 MW.

The Mahakali or Kali along the Nepal-India border on the west joins the Karnali in India [2].The southern rivers has also substantial power potential of 4110MW [13].The table below shows the area, length and discharge of the rivers from where the large and medium power plant are developed of the country [10].

Table 1: main Rivers of Nepal.

SN	River system	Catchment area (Sq.km)	Length of main stream(KM)	Annual mean discharge(m^3/sec)
1	Mahakali	5317	223	557
2	karnali	43227	507	1368
3	Babai	3252	190	72
4	West Rapti	6215	257	126
5	Narayani(Gandaki)	31726	332	1767
6	Bagmati	3681	163	214
7	kamala	1786	117	75
8	saptakoshi	27863	513	1566
9	kankai	1317	108	73
10	Others	22797	-	678
Total		147181		

Condition Assessment of Hydropower Plant

The Table 2 shows the power plants that NEA is currently operating. The plants are classified as large, medium and small project. The plants above 10MW installed capacity are considered as large , 1MW to below 10MW capacity plants are considered as medium and below 1MW are considered as small plants [14]. In this study large and medium plants are chosen for the review study. The main plants chosen for the study are listed in Tables 2 and 3 which includes the design discharge, net head available, installed capacity and the turbine as mechanical unit coupled with synchronous generator of 6.6 kV to 11kv voltage generation level inside power house.

Table 2: Large power plants of NEA,Nepal

SN	Power Plant	Design Discharge(m^3/se)	Head net(m)	Installed capacity(MW)	Type of turbine
1	Kaligandaki	47/turbine	115	144	Francis 3 nos
2	Middle marsyandi	99.5	98	70	Francis 2 nos
3	Marsyandi	30.5/turbine	90.5	69	Francis 3 nos
4	Kulekhani-I	12.1/turbine	550	60	Pelton 2 nos
5	Kulekhani-II	16.65/turbine	284.1	32	Francis 2 nos
6	Trishuli	7.8/turbine	51.4	24	Francis,7no
7	Devghat	14.3/turbine	39	15	Framcis3 nos
8	Gandak	103.84/turbine	6.09	15	Kaplan,3 nos
9	Sunkoshi	39.9/turbine	30.5	10.05	Francis 1 nos
10	Modi	27.5/turbine	66.96	14.8	Fransis 2 nos

Energy Generation Profiles

The Energy generation profile for the large and medium plants tabulated above were generated by taking the monthly Energy generation and total annual energy production of each power plant from the year 2002 to 2017 AD and was compared.

Annual Energy Generation profiles of large power plants

Kaligandaki hydropower plant is the largest plant of Nepal .Its annual power production profile was obtained as in Figure 2.

Table 3: Medium and small power plants of NEA, Nepal

SN	Power Plant	Design Discharge(m³/se)	Head net(m)	Installed capacity(MW)	Type of turbine
1	Puwa	2.5	304	6.2	Pelton 2 nos
2	Seti	12.96	22.5	1.5	Francis3 nos
3	Sundarijal	2.85	22.86	0.64	
4	Chatara	50.9/turbine	6.38	3.2	Kaplan 2 nos
5	Panauti	3.2	60	2.4	Francis 3 nos
6	Fewa	1.36	74.68	1	Fransis 4 nos
7	Pharping	0.25	210	0.5	pelton

The power generation of the plant seemed highly fluctuated. It was low energy generation in the fiscal year 2002 and at 2007. On the year 2015 the production was highest. Figure 3 is energy production profile of the Middle Marsyandi hydropower plant. It was found no operation up to 2009. After repair and maintenance it is now in well running condition and found producing at proper plant factor. The energy production after the year 2065 is in satisfactory level. At downstream of the middle Marsayandi, Marsyandi hydropower plant is developed whose installed capacity is 69.5 MW. Figure 4 is the energy production profile of this plant. During the year production found lowest in the plant. Figures 5 and 6 are production profile of the only one reservoir type hydro power plant Kulekhani-I and II of Nepal. Basically they are used as peak load plant. The production profile showed large variation in generation. It was lowest at the year 2017. As these hydropower are used as peak load plant they supply at peak hour time so the profile shows the demand condition of the country throughout the years. From the Figure 7 the annual production of Modi khola hydropower plant found also highly varied. At the year 2012 it was lowest production. The Sunkoshi hydropower plant was highly affected by earthquake and landslides problems at the year 2015. The earthquake impact was severe on hydropower plant of Nepal. The Figure 8 shows the power production profile of sunkoshi

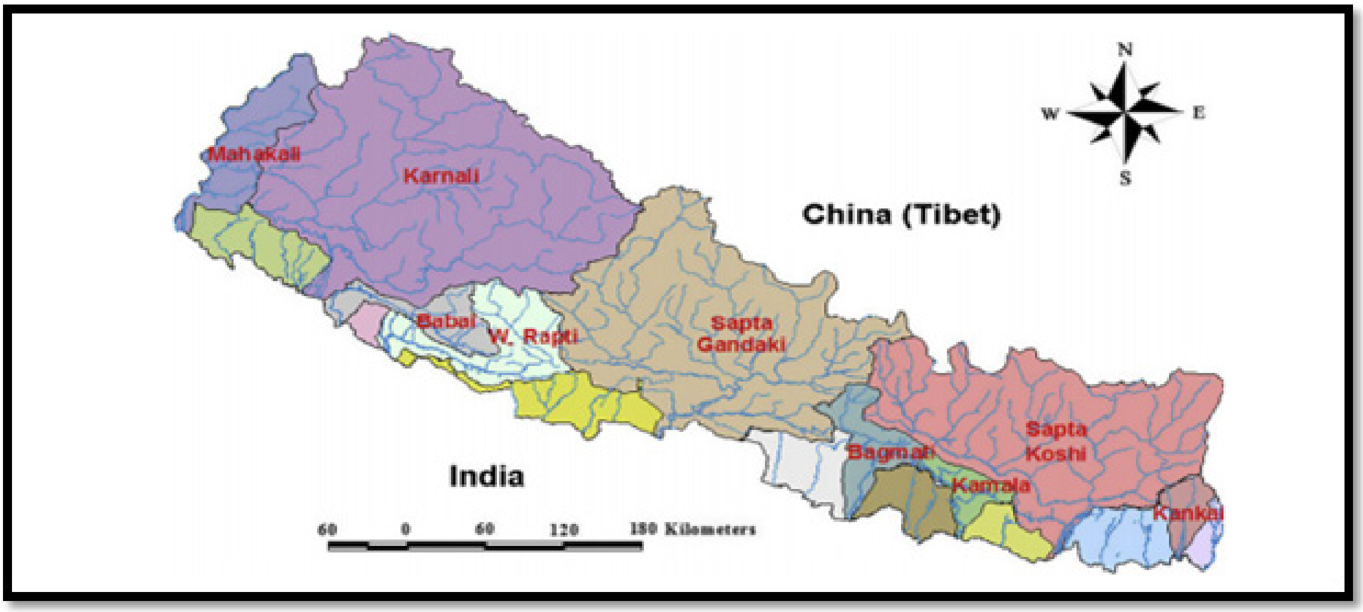

Figure 1(a): River system map generated by ARC GIS

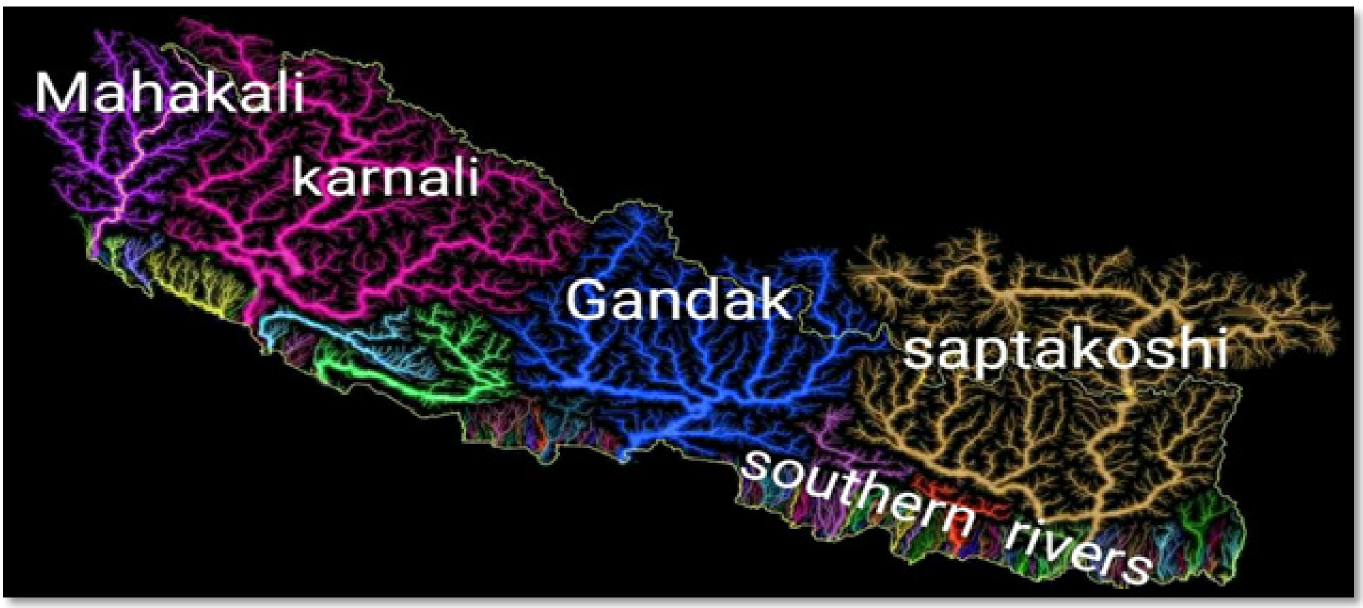

Figure 1(b): River system map of Nepal generated by ARC GIS

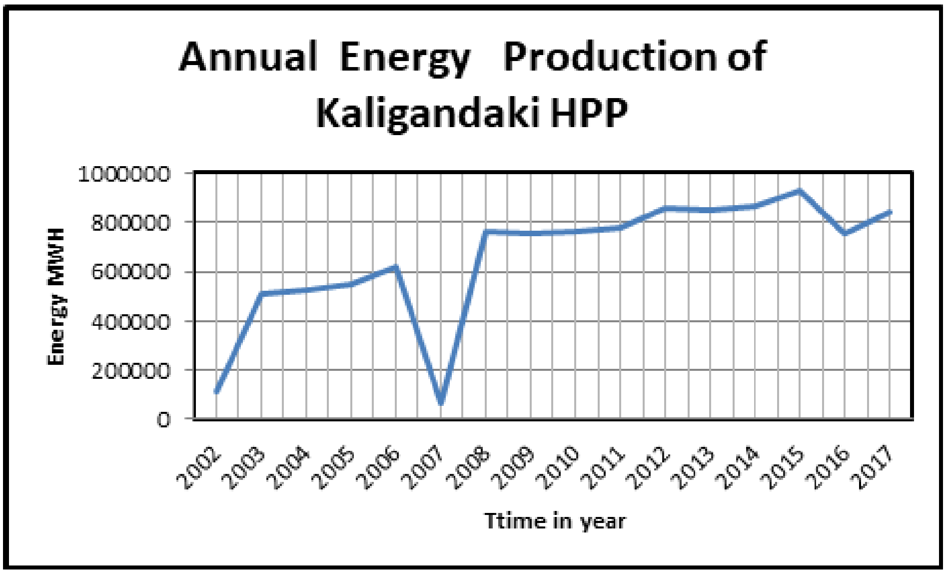

Figure 2: Energy Production Profile of Kaligandaki HPP.

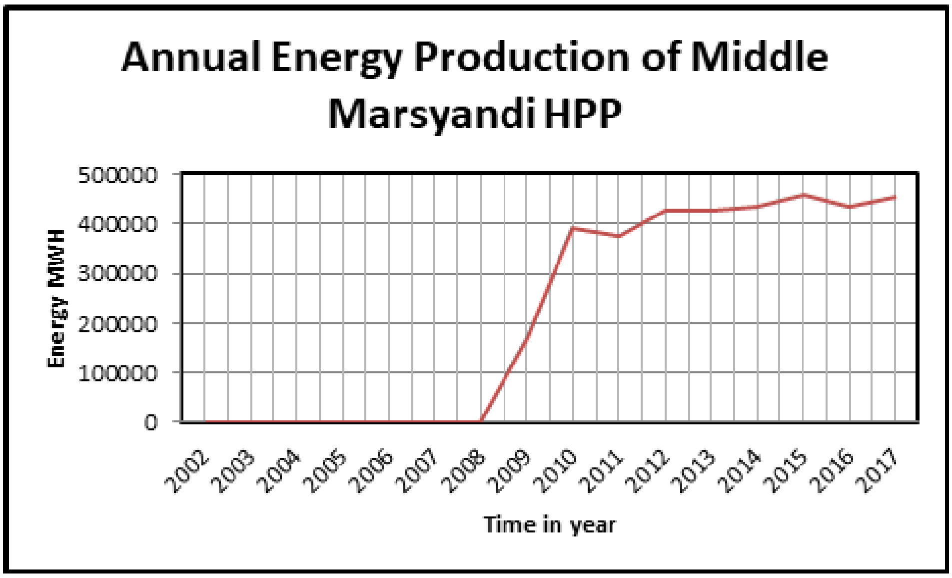

Figure 3: Energy Production Profile of Middle Marsyandi HPP.

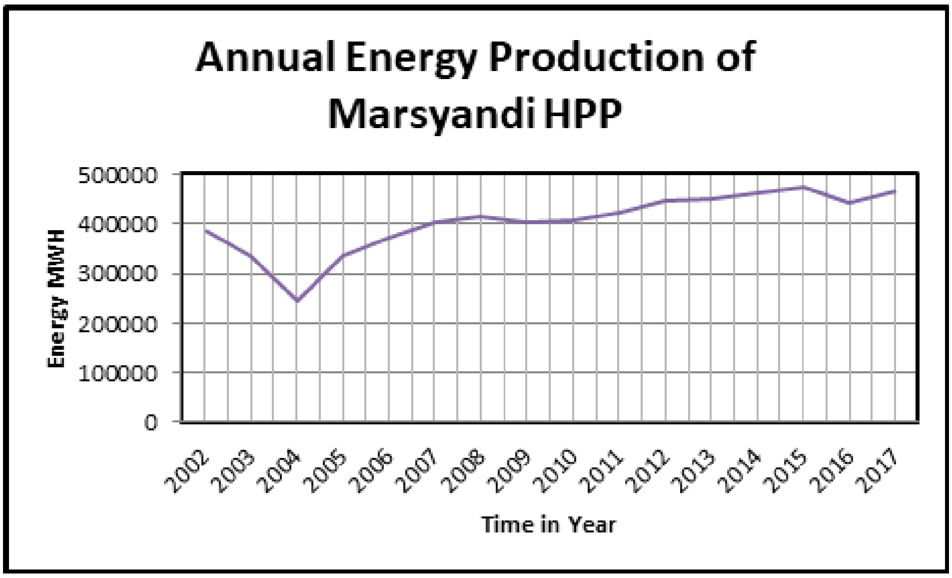

Figure 4: Energy Production Profile of Marsyandi HPP.

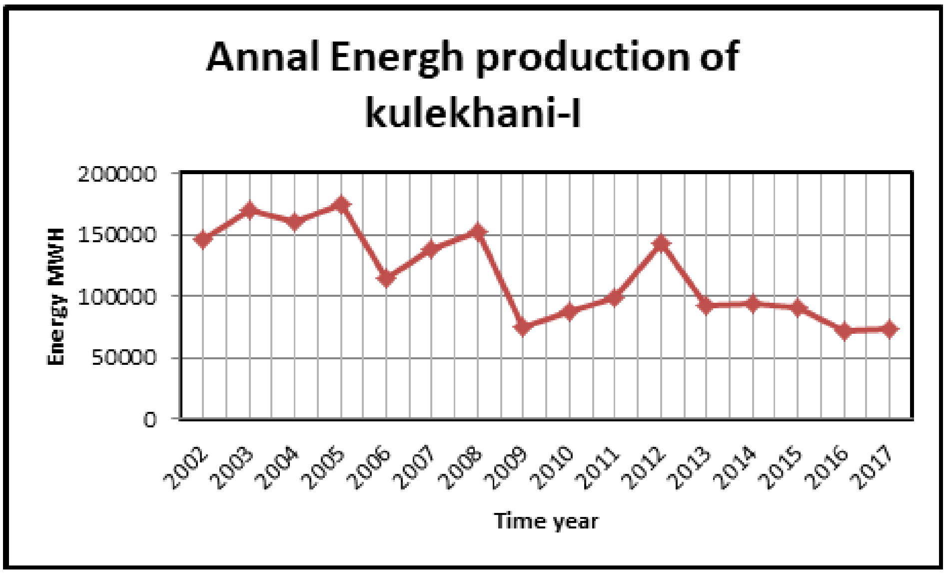

Figure 5: Energy Production Profile of Kulekhani-I HPP

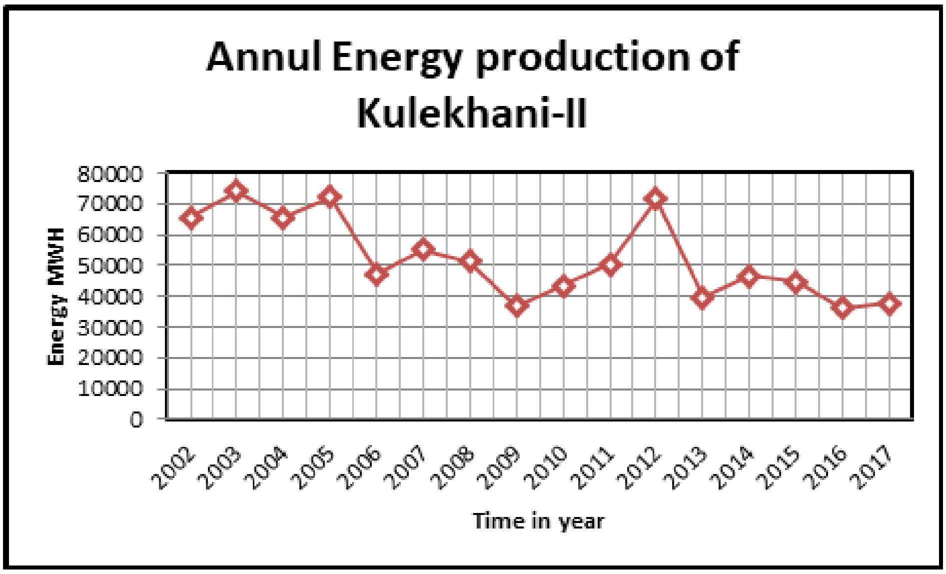

Figure 6: Energy Production Profile of Kulekhani-II HPP

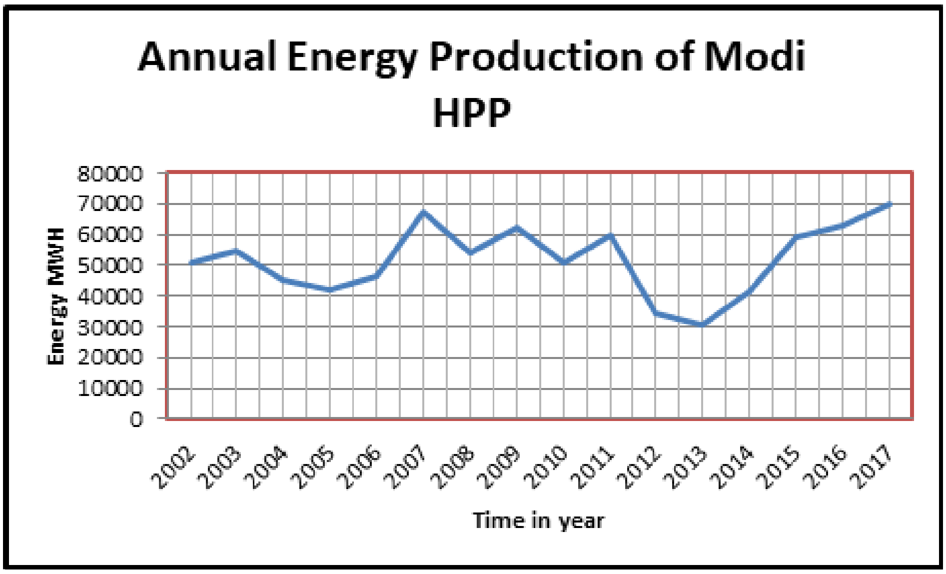

Figure 7: Energy Production Profile of Modikhola HPP

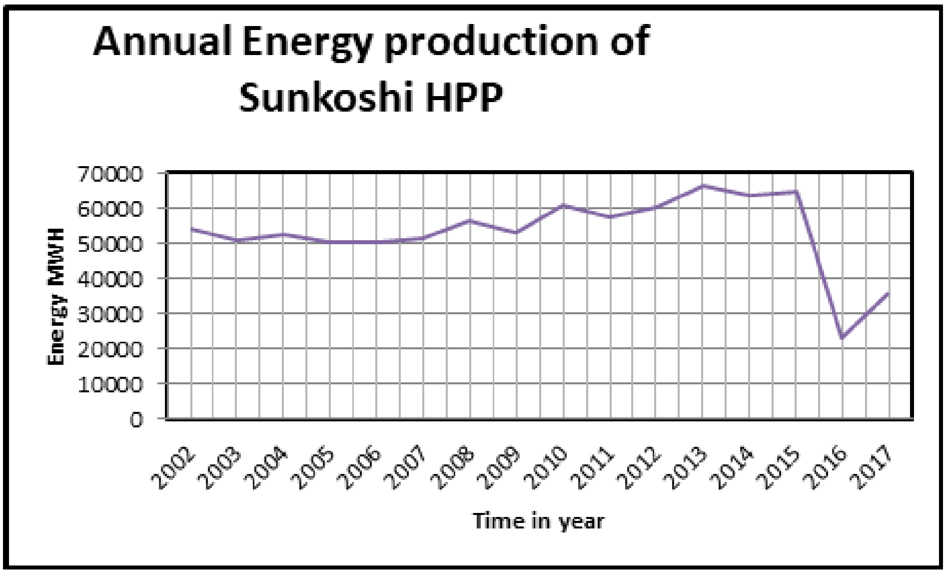

Figure 8: Energy Production Profile of Sunkoshi HPP

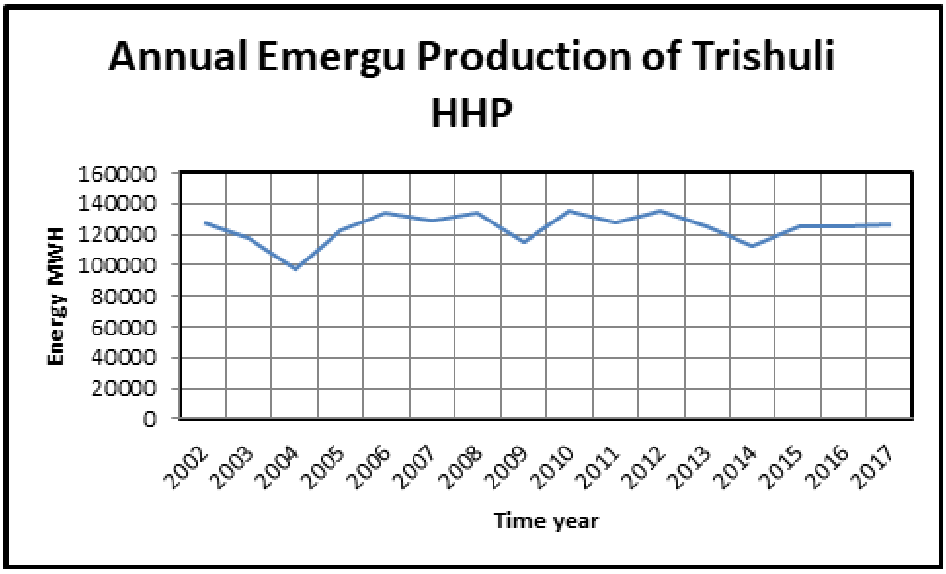

Figure 9: Energy Production Profile of Trishuli HPP

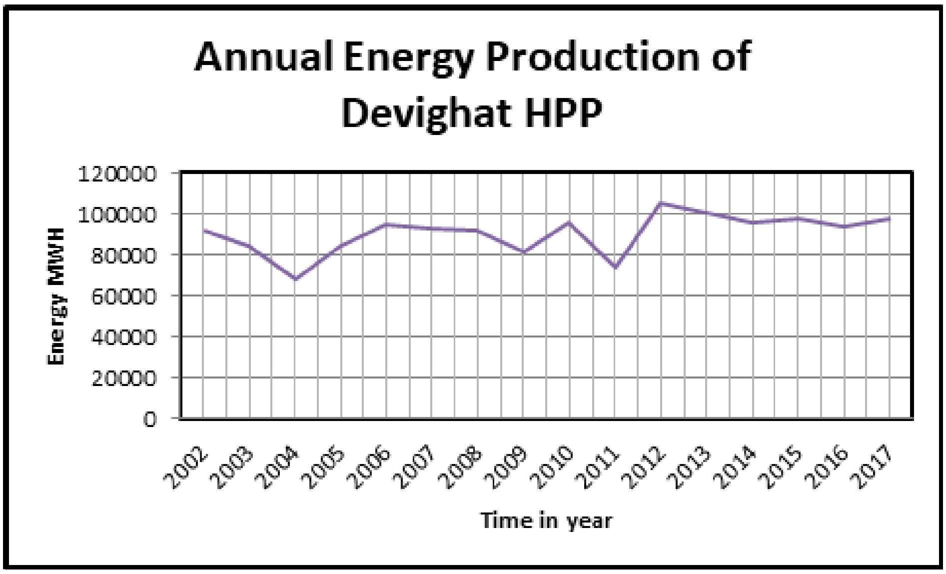

Figure 10: Energy Production Profile of Devighat HPP

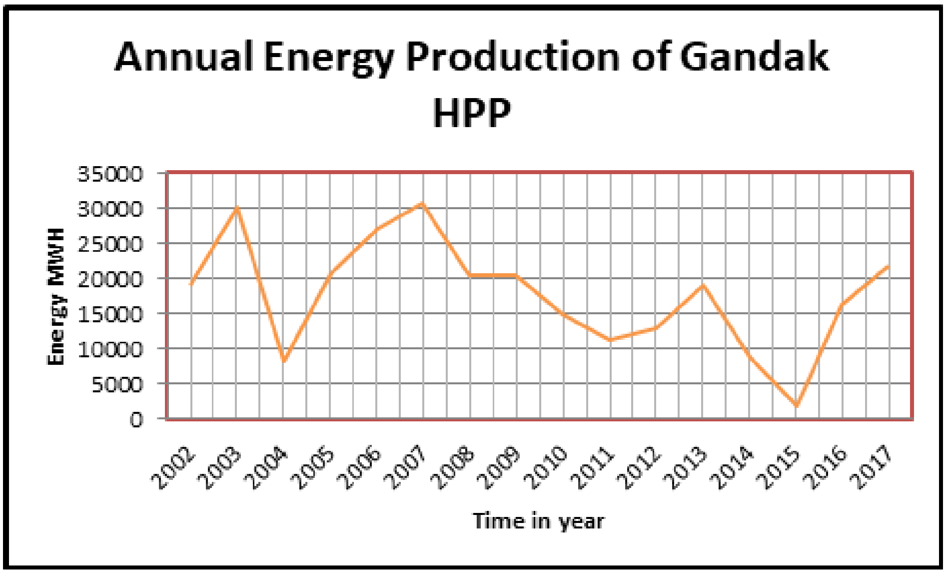

Figure 11: Energy Production Profile of Gandak HPP

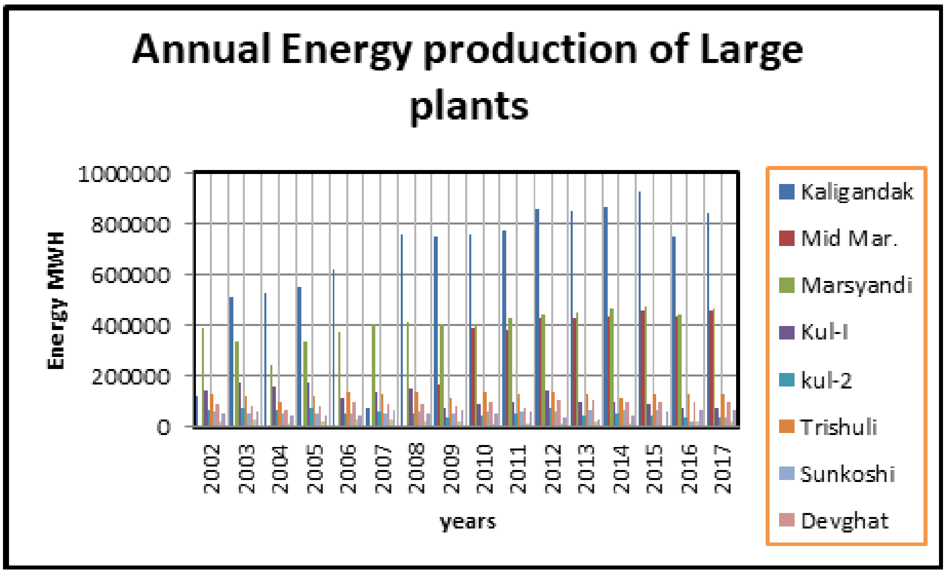

Figure 12: Comparative Energy Production Profile of ten large HPP of Nepal

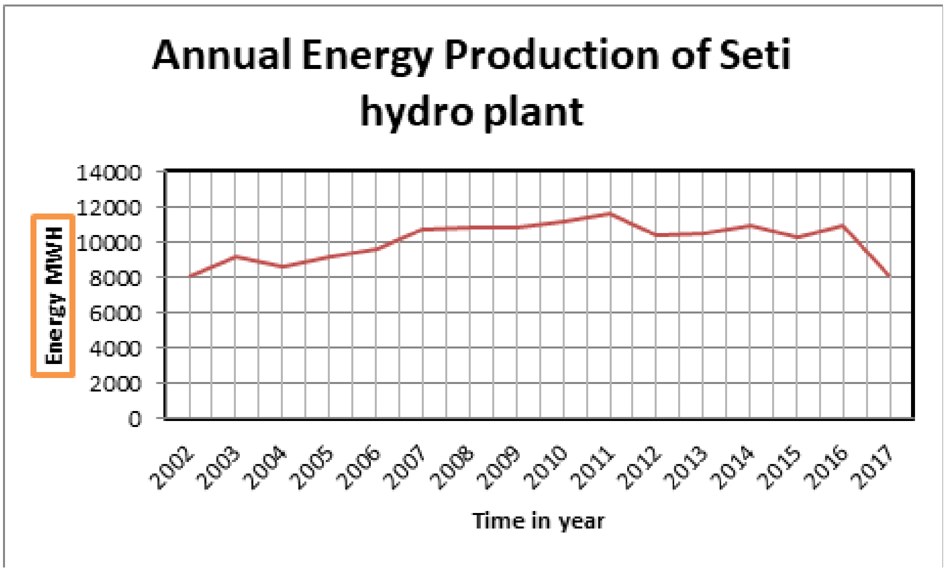

Figure 13: Energy Production Profile of Seti HPP

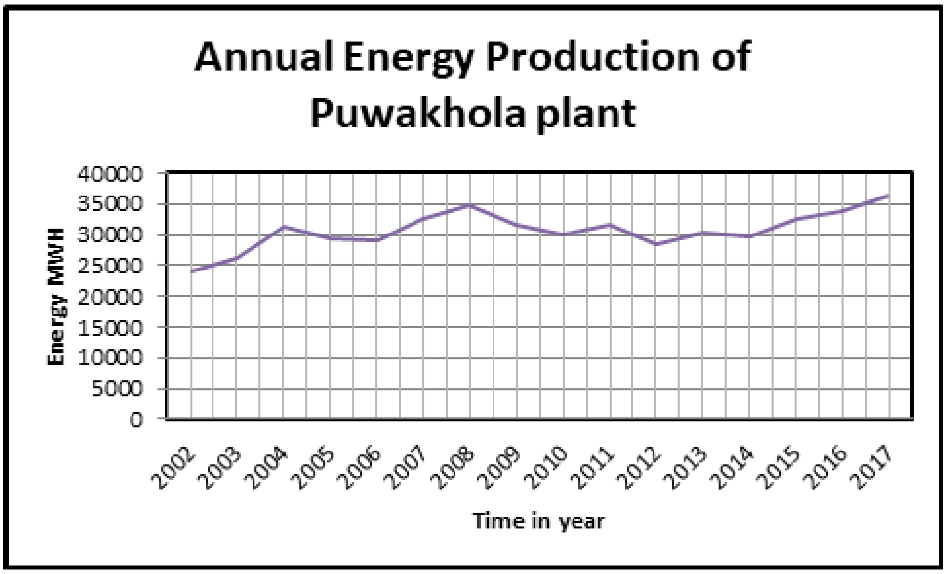

Figure 14: Power Production Profile of Puwa khola HPP

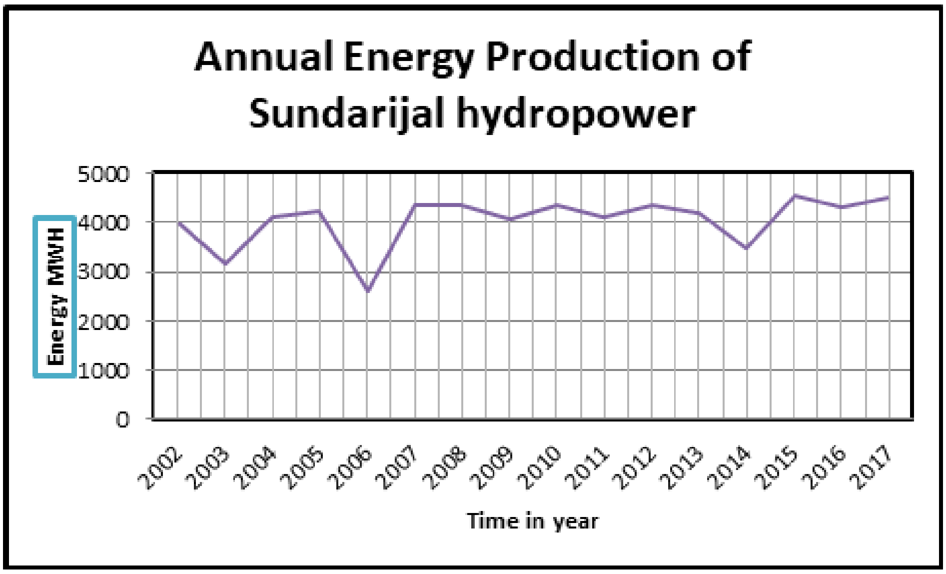

Figure 15: Energy Production Profile of Sundarijal HPP

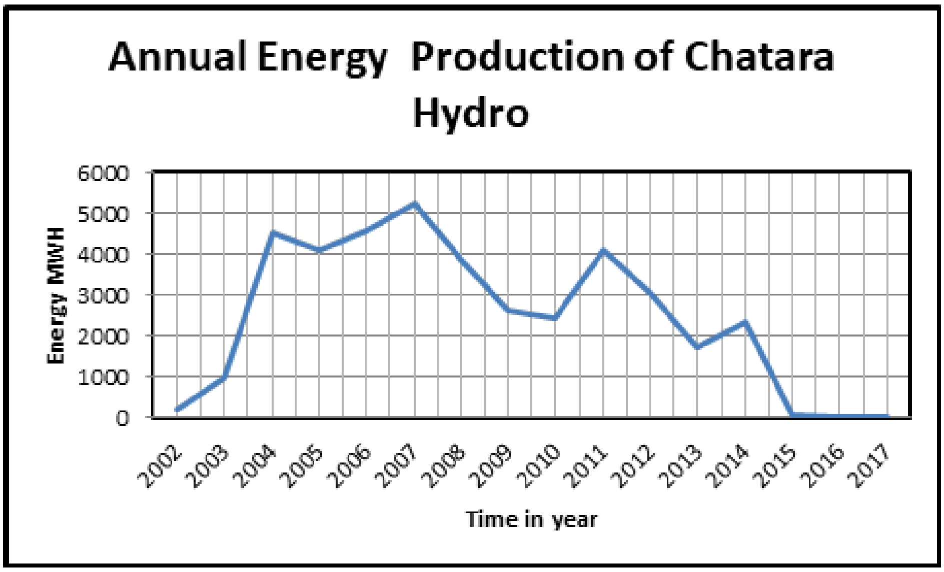

Figure 16: Power Production Profile of Chatara HPP

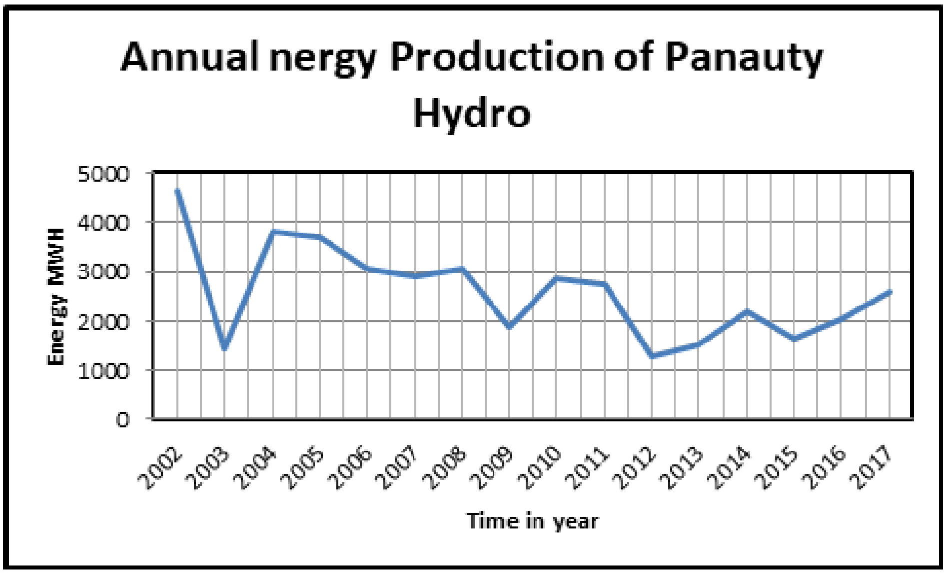

Figure 17: Energy Production Profile of Panauti HPP

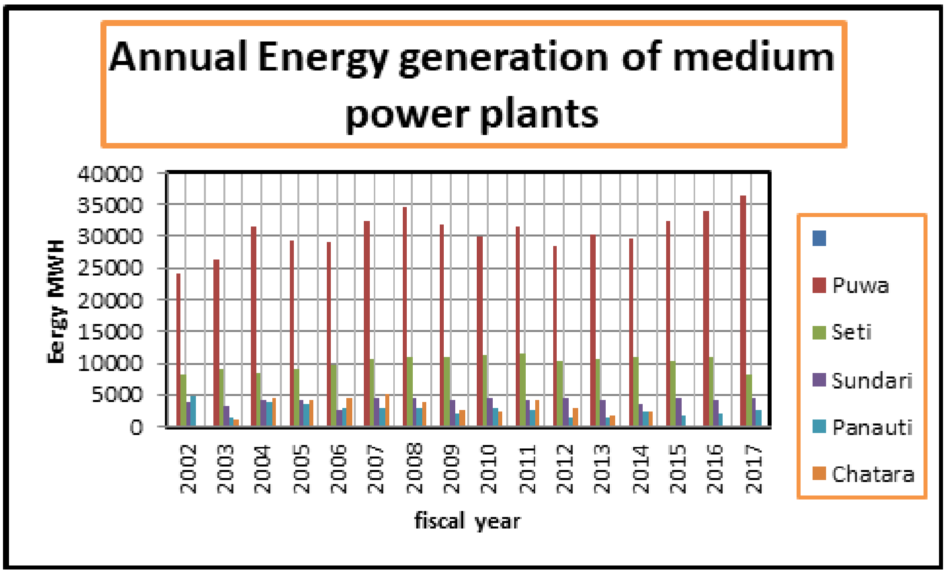

Figure 18: Comparative Power Production Profile of medium HPP of Nepal

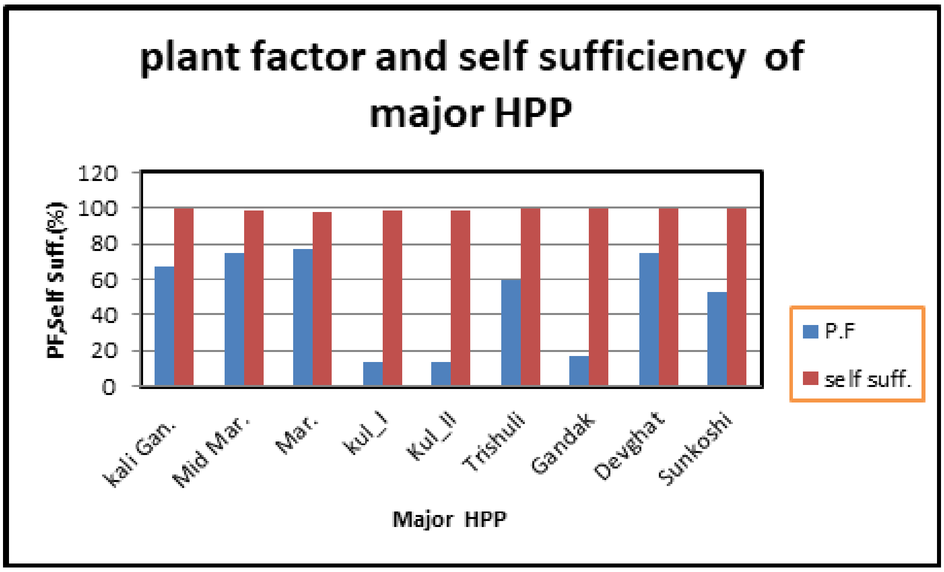

Figure 19: Power factor HPP and self-sufficiency of large HPP of Nepal

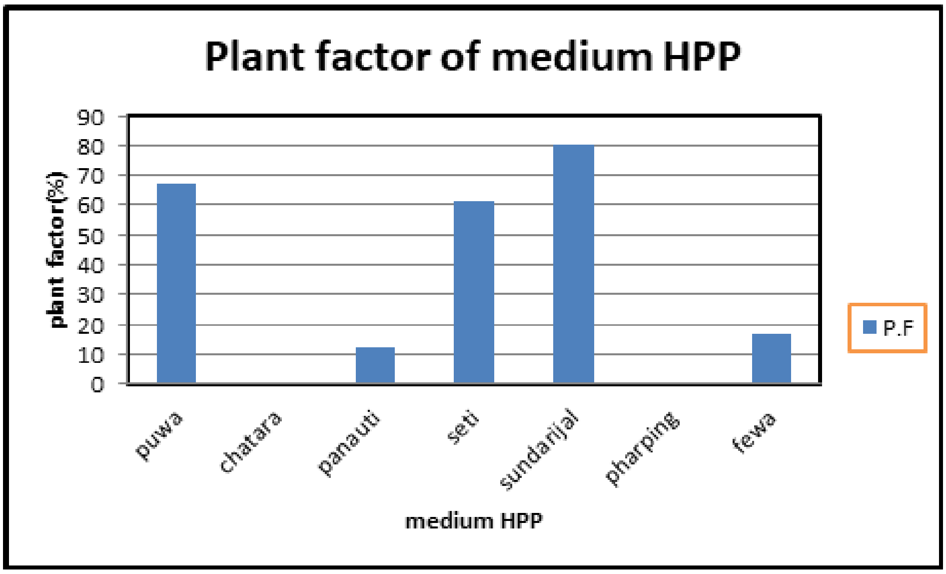

Figure 20: Power factor medium HPP of Nepal

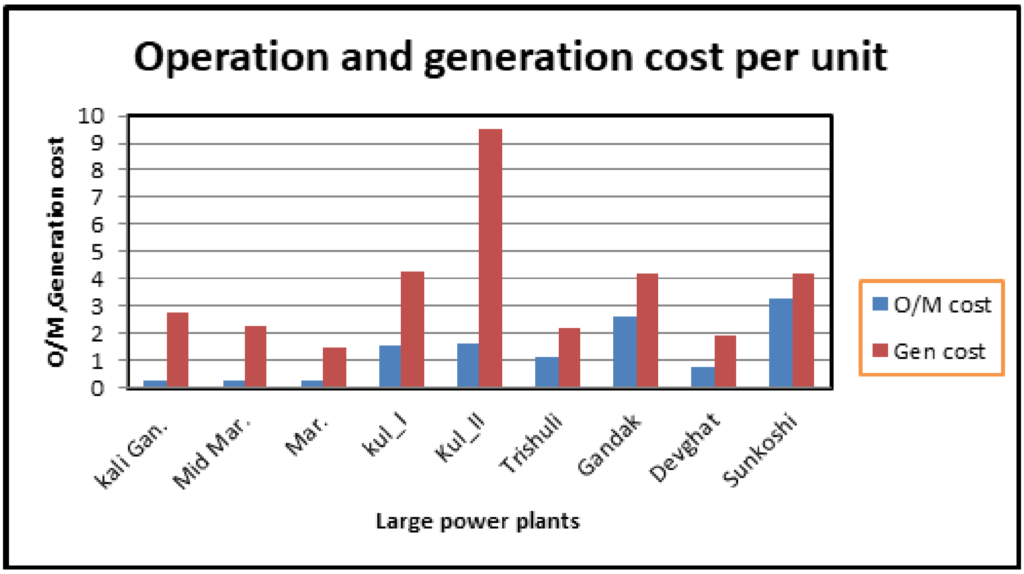

Figure 21: O/M and Energy cost per unit for large power plants

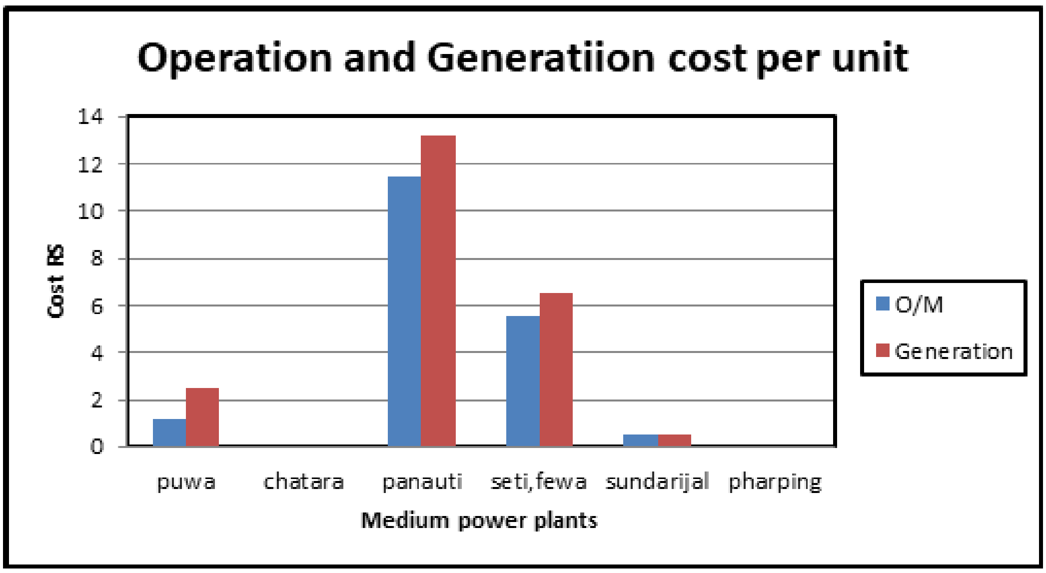

Figure 22: O/M and Energy cost per unit for Medium power plants

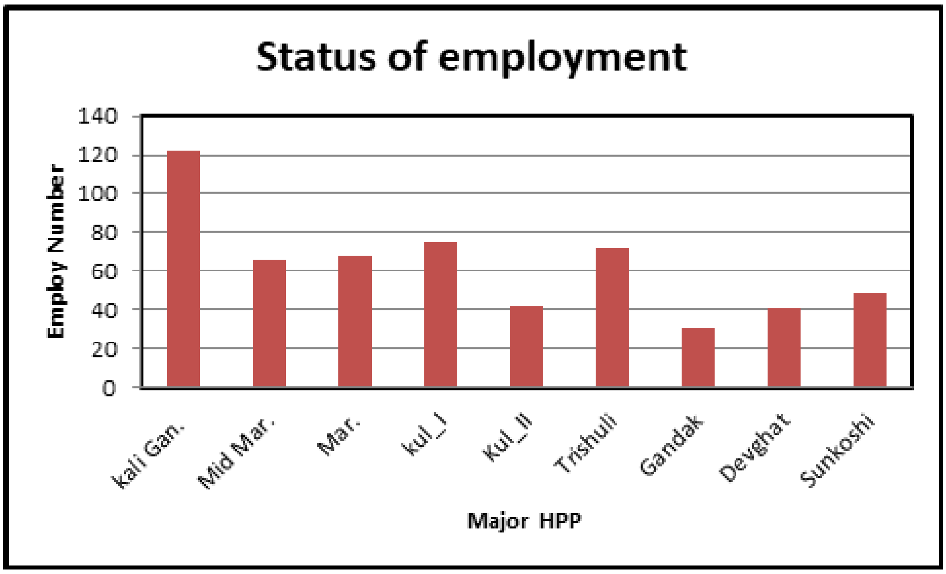

Figure 23: staff level of large power plant.

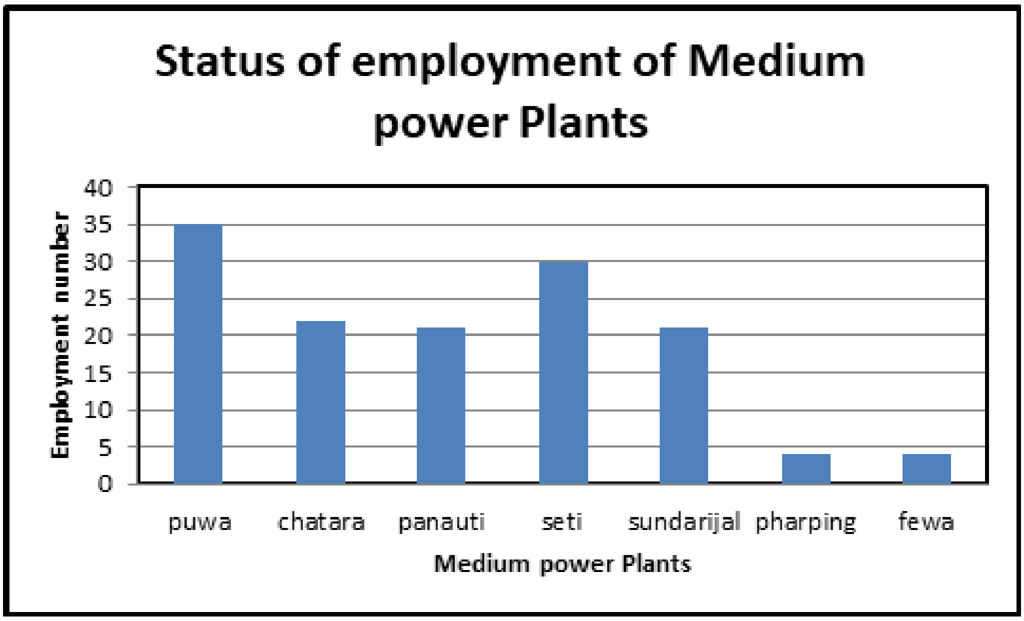

Figure 24: Staff level of medium power plant.

hydro. After repair and maintenance it is operating in its installed capacity now. The energy production profile of Trishuli found more constant in Figure 9. It indicated the well condition of this plant as well. Similarly the energy production profile of Devighat hydropower plant found at less variation during the years. Figure 10 is its production profile. It was found more reliable during the years. Figure 11 showed the highly variation on energy production of Gandak hydropower plant. And Figure 12 is the comparative production profile of the ten large medium power plants whose installed capacity is above 10MW.

Annual Energy Generation profiles of medium power plants

Medium power plants are categorized as installed capacity 1MW and below 10MW. They are originated from the rivers originated from Mahavarat range in southern part of Nepal. Since large power plant development are so costlier and takes long time for construction nation has adopted the medium and small power plant development from the Small Rivers and tributaries. The role of such plants is significant to reduce load shedding and is helping on economic growth of nation at reasonable level. To make the plants sustainable it is felt to review the performance evaluation under certain issues. The energy production profile of main plants was evaluated of time series 2002 to 2017. From the analysis the production profile of Seti hydro was obtained in Figure 13. During the years the production found not much variation and plant is found sustainable and reliable with good efficiency, plant factor. Similarly the Figure 14 is the production profile of puwakhola of east Nepal. From the figure could be understood the plant is in very reliable and well operation condition as the power generation is not much varied over the years. But the Figure 15 showed more variation in power generation in case of Sundarijal hydro plant. The hydropower developed in Chatara irrigation canal of Province 1 of Nepal is an example to use the canal water in plain region. Due to high sediment flow in canal and difficult to manage sediment deposition power plant operation is irregular. The Figure 16 showed no power generation from the 2071 year which is loss in energy and economic growth as it is supplying power to local areas of the province at large area for domestic use. The Panauti hydro is also contributing substantial amount of power however its power generation profile Figure 17 showed variation in annual power production. Figure 18 is the comparative power profile of the plants.

From the analysis both large and medium power plants are contributing in energy generation. As most of the plants are peaking run off river type we can make the plants more sustainable by enlarging the storage capacity and proper management of the sediment of the river in reservoir. The risk from change in environment and climate are to be considered for the best site selection before power plant development. The nature hazards like landslide and earthquake are hazardous too. It must be considered during the construction so that sustainable power generation will be possible.

Performance Evaluation

For performance evaluation, MCDA indicators parameters like plant factor and self-sufficiency were calculated of each plant. The Figure 19 shows the parameters of the plants from which the Marsyandi is found working at high plant factor and Kulkarni has low power factor. Self-sufficiency is seemed in same condition of each plant. Similarly in case of medium power plant the Seti, Sundarijal and Puwa khola are found working at high plant factor whereas the Phewa, Panauti are found at low plant factor and Chatara is found at no operation condition. Figure 20 is the comparative chart of plant factor for medium plants.

Economic Efficiency

The suitability and sustainability in terms of cost per unit energy production were observed. Figure 21 shows the comparative production cost of the large power plant. Kulekhani –II has the highest production cost (9.5 NRS/unit) which is high generation cost and Marsyandi has lowest cost for unit energy generation. Similarly the operation and maintenance cost found highest for Sunkoshi hydropower plant and lowest for Kaligandaki. Similarly in case of medium power plant Panauti has highest O/M and energy production cost (13NRS/unit) which is very high generation ccost. And Sundarijal is working at lowest cost for both O/M and generation. The Figure 22 is the comparative chart for medium plants.

Staffing level

This parameter is used for the analysis of employ needed for unit power production. Kaligandaki has highest number of employee but its manpower per unit power generation is low. In case of Sunkoshi it is highest. So the Kaligandaki is running at low staffing level. Figure 23 is the employment level of large power plants. In case of medium plants Chatara has highest manpower required for unit power generation and Sundarijal has lowest staff working for unit power production. Figure 24 is the staffing level of medium power plant.

CONCLUSION AND RECOMMENDATIONS

From this study of the performance evaluation of large and medium power plants some conclusions could be made. The energy production profile of large power plant showed the Marsyandi hydropower plant is working comparatively in good condition .Its energy production cost is low and minimum staff level. Whereas the middle Marsyandi remained closed during long period from 2002 to 2009 which was huge loss period for country economically. The only one reservoir type plant kulekhani plant found working at low plant factor and high energy generation cost. The operation and maintenance cost is also highest for these plants. Among the medium power plant Seti hdro, puwa khola and panauti hydro are found in good condition working at satisfactory level however the energy production cost is found high at Panauty hydro plant.' Most of the plants owned with Francis turbine and largest plant Kaligandaki is affected by sediment problems whereas Sunkoshi hydro found affected by natural hazards landslides and earthquake. In case of medium power plant Chatara hydro is at very poor working condition so needs repair and maintenance as soon as possible as energy loss means huge economic loss for poor country like Nepal. From the study the power which is generating energy at high cost must be improved so that generation cost will be low. The factors affecting for high cost should be identified and optimization of the power plant operation is necessary.

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