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Hydropower Development in Nepal - Climate Change, Impacts and Implications

Ramesh Prasad Bhatt

Additional information is available at the end of the chapter

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Abstract

Nepal has endowed high potential of water resources, covering 395,000 ha (48%) area within 45,000 km in length of 6000 rivers with 170 billion m³ annual runoff and 45,610 MW feasible hydroelectricity generation. Since 1911, 500 kW power generation at Pharping, now reached 782.45 MW production in 2016. Nepal government has planned to increase its current 67.3% access in electricity to 1426 MW (87%), by 2022. Globally, 16.6% generation of hydroelectricity, 1,079 GW production, in 2015 will be increased to 1,473 GW by 2040 as projected. Although, hydropower is considered as a renewable clean energy, dam closure, influence within the downstream river and connected ecosystems have consequent impacts on hydropower production. Nepal's topography offered more RoR types of hydropower and has more risk of landslide, flooding, GLOFs, LDOFs, and flash floods. Despite, Nepal contributes 0.027% of total global Green House Gas (GHG) emissions; Nepal has focused on renewable energy, hydropower production, targeting 12000 MW by 2030 to fulfill its growing demand of 11,500 MW. Consequent development of clean energy, GHG reduction, single Bhotekoshi hydropower can reduce 160092 tons CO₂/year. The energy-related CO₂ emissions increased 43.2 billion metric tons by 2040 globally, which can be reduced through promotion of clean energy.

Keywords: Water Resources, Hydropower Development, Bhotekoshi Hydropower, Renewable Energy, GHG Reduction, Downstream Impacts

1. Introduction

Nepal has endowed high potential of renewable water resources, possessing about 2.27% of the world's fresh water resources [1]. Most of the rivers flowing from Nepal Himalayas covers

818,500 ha land area equivalent to 5%, out of the total surface area of the country [2]. In total, Nepal possesses 6000 rivers including rivulets and tributaries in totaling of about 45,000 km in length and covering an area of 395,000 ha (48%) [3] and offering dimensional uses including hydropower development [4]. There are 33 rivers having their drainage areas exceeding 1000 km² [4] and all the rivers in Nepal comprise the total drainage area of about 194,471 km² and the rest in China and India. The annual average discharge of the Nepalese rivers is about 7124 m³/s including the total basin area and about 5479 m³/s excluding the area outside of Nepal [5].

Nepal's river has a storage capacity of 202,000 million m³, which includes about 74% amount from three major rivers, Koshi, Gandaki, and Karnali. Geographically, perennial nature of rivers estimated an annual runoff accounting up to 170 billion m³ that flows from steep gradient and rugged topography and estimated 45,610 MW, feasible for hydropower generation which is equivalent to 50% of the total theoretical potential of 83,290 MW [6]. The hydropower system is dominated by run-of-river schemes in Nepal while storage schemes have been benefited to control flood, provide irrigation facility, drinking water supply, navigation, recreation, tourism, aquaculture, and generate revenue [7]. From the beginning, hydropower is used as the natural water-cycle-based renewable energy, which is reliable, most mature, and cost-effective technology of power generation [8]. The discharge and river flow depends on the catchment area, rainfall pattern, and the volume of the water estimates the mechanical energy produced by the falling or flowing water called hydropower.

The source of energy shares from a conventional source in Nepal is 87% as a significant share of electricity and renewable energy with 56.1% households have access of electricity [9]. Hydropower is the main source of energy in Nepal, nearly 90% installed capacity and 90% generation of electricity. The country status report showed that Nepal's energy sources supplied mostly from traditional resources such as firewood (75%), petroleum products (9.24%), animal waste (5.74%), agricultural residue (3.53%), electricity (1.47%), and other renewable resources (0.48%) [10]. Nepal Electricity Authority (NEA) has a total installed capacity of about 746 MW [11] and 26 MW operating from mini and microhydropower plants in the hills and mountains of Nepal [12]. There is a significant energy deficit due to the poor economic and instable government to continue the electricity supply. However, the country has three strategic considerations for exploring large-scale hydropower like storage types of projects, to fulfill country's required demands through installation of medium-sized projects and finally small hydropower projects targeting to fulfill demand of the local communities.

Hydropower is an environment friendly source of energy with no pollution emitting in air or in land, and it also the most efficient method to all. Thus, traditionally hydropower has been considered environment friendly that it represents a clean and renewable energy source.

The multipurpose use of water as fresh water, agricultural, industrial, household, recreational, and environmental and power generation, Nepal's water demand is increasing day by day. Nepal has built several dams for hydroelectricity and irrigation purposes [13]. The human influence with population growth, affluence increase, business activity expansion, and rapid urbanization persuade climate change issue seriously resulting depletion of aquifers and health effects with increasing water pollution. The country's fragile environment consisting rugged topography, monsoon climate, juvenile geology results high rates of runoff, erosion,

landslide, sedimentation, and flooding. The climate change problems and issues are related to the resource impacts concerning the geographical and ecological characteristic of the country. The water resource impact evaluation is challenging toward water availability, quality and stream flow, and sensitive to changes in temperature and precipitation [14]. According to Ref. [15], “inflow of precipitation in the basin depends on the upstream rainfall and snowfall” and affects river regimes in different environmental factors at various timescales like seasonal, monthly, daily, and hourly. Similarly, large-scale hydropower projects may have greater economic and environmental implications. However, the impacts on specific ecosystem of each hydropower depend on the size and flow rate of the river or tributary, climatic, and habitat conditions, type, size, design, and operation of the project, and nature of cumulative impacts that occur upstream or downstream of the river.

2. Material and methods

2.1. Location

Nepal is a land locked and least developed country, occupying 147,181 sq. km total land area, lies between 26°22" and 30°27" N latitudes and 80°04" and 88° 12" E longitudes with north to south of 193 km width and 885 km average stretch from east to west [16]. The country's varying topographic and climatic conditions from south tropical to alpine in north with 80% of the annual rainfall in summer season, distributing both from north-south and east-west directions. Three major river systems originate from across the Himalayan range divided in Nepal from east to west the Koshi, Gandaki, and Karnali River, major tributaries of the Ganges river in northern India.

2.2. Upper Bhote Koshi hydropower: a case study.

The Upper Bhote Koshi Hydroelectric Project (HEP) is a run-of-the-river scheme constructed on the Bhote Koshi river, a tributary of the Sun Koshi river, in Sindhupalchowk district of central Nepal. It is located approximately 110 km northeast of Kathmandu near the Sino-Nepal border; the Project has a head work with a side intake approximately 500 m downstream of the confluence of the Bhote Koshi river and the Jung Khola near Tatopani VDC (**Figure 1**). Water diverted from the side intake is conveyed to a surface powerhouse through a headrace conveyance system comprising a surface desanding basin located adjacent to the weir, a 3.3-km-long headrace tunnel, a restricted-orifice-type surge tank, and a 450-m-long, 2.8-m diameter steel penstock. The Project has an installed capacity of 45 MW, with two turbines/generator units; however, the project is generating 36 MW as per Power Purchase Agreement (PPA) according to the Nepal Electricity Authority (NEA). The Plant was synchronized to the NEA grid on January 3rd, 2001, and commercial operation started on January 24th, 2001. The plants salient generation features are as follows:

- Total generation: 224.970 GWh, 85.2% deemed max.
- 91.5% of estimated average annual generation, plant outages 5.639 GWh (97.7% availability)

- NEA outages 11.046 GWh (95.4% availability)
- Total plant and NEA outages 16.685 GWh (93.1% availability).

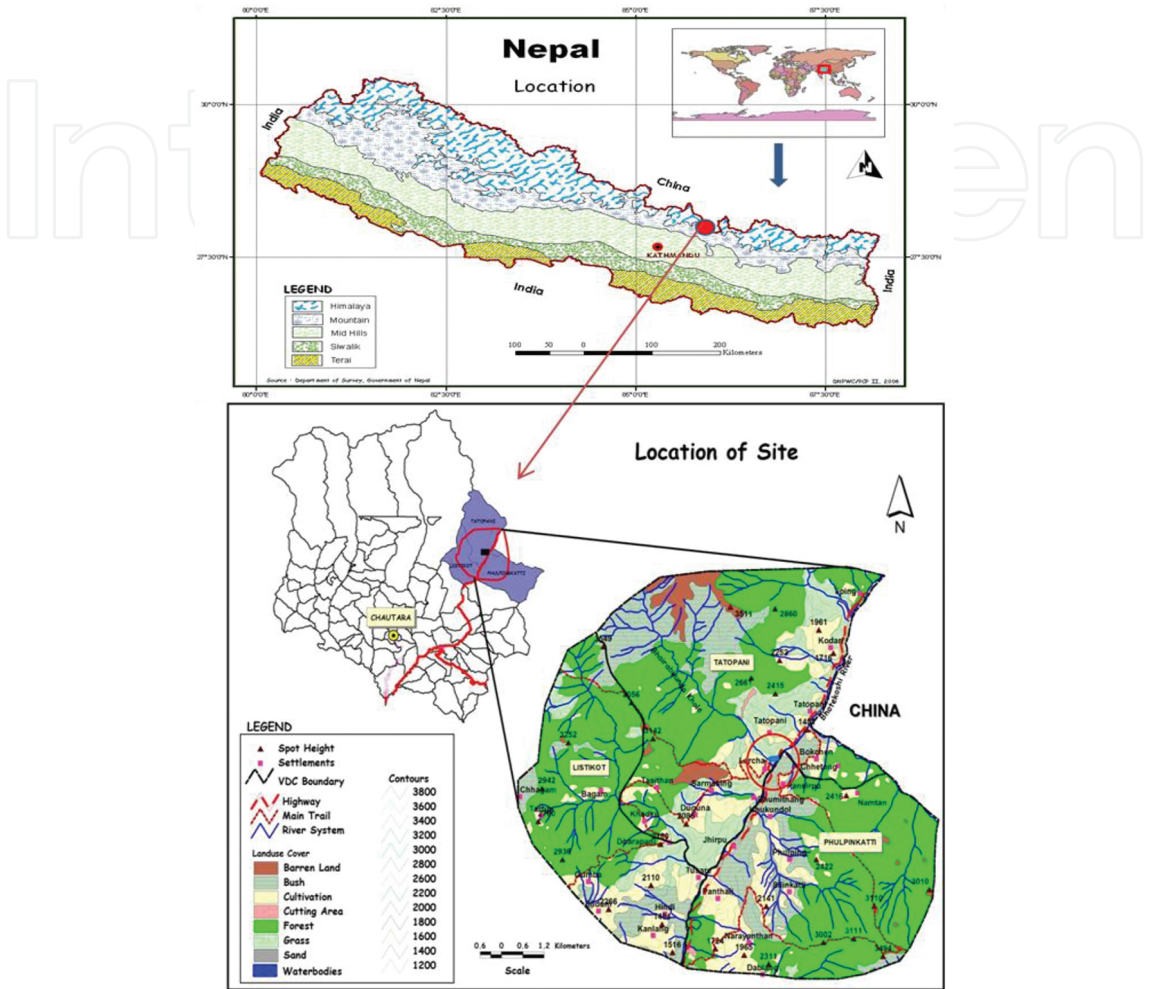


Figure 1. Location of UBHP: a case study area.

2.3. Data

All data used in this chapter were obtained from baseline studies, research, plan and policies, sectoral guidelines and strategies, case studies, and reports. The collected data were compiled, crosschecked, and analyzed from history of hydropower development to current scenario consisting impacts and implications as well as their planning, statistical analysis/downscaling, computational simulations and development of indicators, modeling and projections.

2.3.1. Policies and legal instruments

The policy and legal instruments relevant to hydropower development were reviewed and presented considering the energy issue and analyzed policy level impacts and implications of Nepal's HEPs.

2.3.2. *Technical review, Analysis, Projection and Modeling*

The relevant data were collected from various sources such as Government of Nepal/ Water Energy Commission Secretariat (GoN/WECS), Department of Electricity Development (DoED), Nepal Electricity Authority (NEA), Department of Hydrology and Meteorology (DoHM), and other hydropower developing agencies. To analyze the baseline scenario of the hydropower project at the national and global level, collected data were computed, projected, and assessed including web-based information. For hydropower generation, analytical methods and procedures engineering toolbox were used to determine and crosschecked the potential capacity of water resources, available power, efficiency, river flow, power generation capacity, hydroelectric power, and hydroelectric energy. The measurement of water discharge has quantified with comparison of hydrological data and modeling, impacts and implications on hydrology, and flow regime including climate change impact modeling and projections as per the Intergovernmental Panel on Climate Change (IPCC) guidelines. For case comparison, existing overview of the hydropower development, climate change issues, impacts and implications including future scenario with GHG emission and reduction has synthesized from different hydropower's in Nepal, emphasizing details of upper Bhote Koshi hydropower project.

3. Hydropower baseline and electricity generation

The electricity generated by hydropower was 16.6% of the total world's electricity, which is 70% of all renewable electricity [17] and about 3.1% projected to be increased yearly for the next 25 years. The increasing rate of global population by around 1.5 billion projected to be 8.8 billion by 2035 needs 34% increase in energy consumption between 2014 and 2035. The total 549 quadrillion British thermal units (Btu) of world's energy consumption in 2012, would increase up to 815 quadrillion British thermal units (Btu) in 2040 with an increasing ratio of 48% [18]. The average generation capacity of hydro, geothermal, and biomass electricity has fluctuated around 42–43% and the average capacity utilization rate will be 43% for the period of 2016–2040 [19]. The generating capacity of renewable sources of energy like hydropower, geothermal, and biomass 1079, 14, and 52 GW in 2015 will considerably increase globally to 1473, 132, and 275 GW, respectively, as projected for 2040 [20]. Among the renewable source of energy in Asia, hydropower has significant potential with installed capacity of 542 and 2204 GW potential.

The history of hydropower development in Nepal began on May 22, 1911 (9 Jestha 1968 BS) by installing 500 kW electricity at Pharping named as Chandra Jyoti. After 25 years, long duration, Prime Minister Dev Shamsheer initiated 640 kW, Sundarimal Hydropower plant with a capacity of 900 kW in 1936. Sundarimal, hydroelectricity development in Nepal was once again stalled for decades. Some years later, Morang Hydropower Company established in 1939 and completed construction of third Letang hydropower plant with an installed capacity of 1800 kW in AD 1943 under public-private partnership. The plant supplied electricity to Biratnagar Jute Mill and later destroyed by landslide [21, 22]. Historically, however, Nepal's first bilateral

agreements with India were Koshi and Gandak Projects in 1954 and 1959, respectively, exclusively designed to cater for irrigation and flood control in India with small irrigation and hydropower component for Nepal.

During the late 1960s, a hydropower plant was constructed with foreign assistance such as ex-USSR (Panauti-2.4 MW), India (Trisuli-18 MW, Devighat-14.1 MW, Gandak-15 MW, Surajpura-Kosi-20 MW), and China (Sunkoshi 10 MW, built in 1972 as a gift to Nepal from China). The 92 MW Kulekhani Hydropower Plant (I and II) was commissioned in 1982, which is the only project offering seasonal water storage in Nepal. The 144 MW Kali Gandaki A hydropower project, commissioned in 2003 is the biggest hydropower project in Nepal so far. In 2005, a plan to develop Kaligandaki-Nawalpur diversion (multipurpose) project (with about 20 km tunnel) to generate 22 MW of electricity was formulated but it could not be materialized.

The growing demand of electricity was estimated to be 557 MW in 2005 to 1200 MW in 2013. In 2013, there was 733 MW hydropower out of 782 MW installed capacity including NEA that owned 478 MW capacity of hydropower and 255 MW operated from the private sector. Similarly, electricity demand estimated 105 GWh in 2006/2007 and increasing to 678 GWh in 2009/2010, with the temporary peak in 2008/2009 with 745 GWh. Thus, the problem was mainly due to all hydropower plants which are RoR types except the capacity of 92 MW of storage type [23]. The estimated electricity demand growth rate will be 8.34% increasing from current growth demand 4430 GWh annually to the system peak load of 17,400 GWh with the annual growth projection of 3679 MW by 2027 [24].

Particulars	Fiscal year				
	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015*
Production (MW)	697.85	705.57	746	746	782.45
Transmission line (km)	1917.62	1987.36	1987.36	1987.36	1987.36
Customer number	1,854,275	2,053,259	2,599,152	2,713,804	2,789,678
Distribution line (km)	89,108.86	95,815.98	11,4160.40	116,066.64	116,090.64
Available energy (GWH)	3389.27	3858.37	4260.45	3092.47	3228.9
High demand (MW)	946.1	1026.00	1094	1200.98	1291.1
Demand supply gap (MW)	248	320.43	348	454.98	508.65

Note: *Of the first eight months.
Source: Ministry of Energy, 2016.

Table 1. Electricity demand, consumption, production, and physical structures.

Nepal has an estimated 42,000 MW hydropower potential, 100 MW of microhydropower, 2100 MW of solar power for the grid, and 3000 MW of wind power renewable energy commercially exploitable. Nepal’s ninth plan addressed to generate 22,000 MW electricity by 2017 and other studies estimated 10,000 MW within 10 years and 17,000 MW by 2030. The policy of government for small hydropower generation from 1 to25 MW has focused on providing incentives

to local institutions/organizations and promoting the development of medium hydropower from >25 to 100 MW for national private sectors and seek support for large hydropower projects. The electricity generation in FY 2013/2014 was 746 MW, which increased by 4.98% (782.45 MW) in 8 months of the year and 1987.36 km transmission line has been extended. The electricity consumers have been increased 2,789,678 in the number and 116,090-km-extended line of electricity distribution. The total demand of the electricity 1291.1 MW has limited to just 782.45 MW by the end of the year (Table 1).

The hydropower development started from 1911 generating 1.1 MW electricity, before first five year plan and consequent development in the thirteenth plan which targeted to 668 MW hydropower generation in 2018. The growing energy demand has estimated at 11,500 MW by 2030 for moderate GDP growth (5.6%) and higher demand for GDP growth of >8% . Thus, the existing policy and legal arrangement need to be put in a place, considering the present situation for the sustainable development of hydropower for the overall development of the country. As per the WECS energy strategy 2012, clean energy technology (CET) scenario, in which the fossil fuels should be decreased by 20% by 2020 and 30% by 2030. The produced and targeted electricity generation is shown in Figure 2.

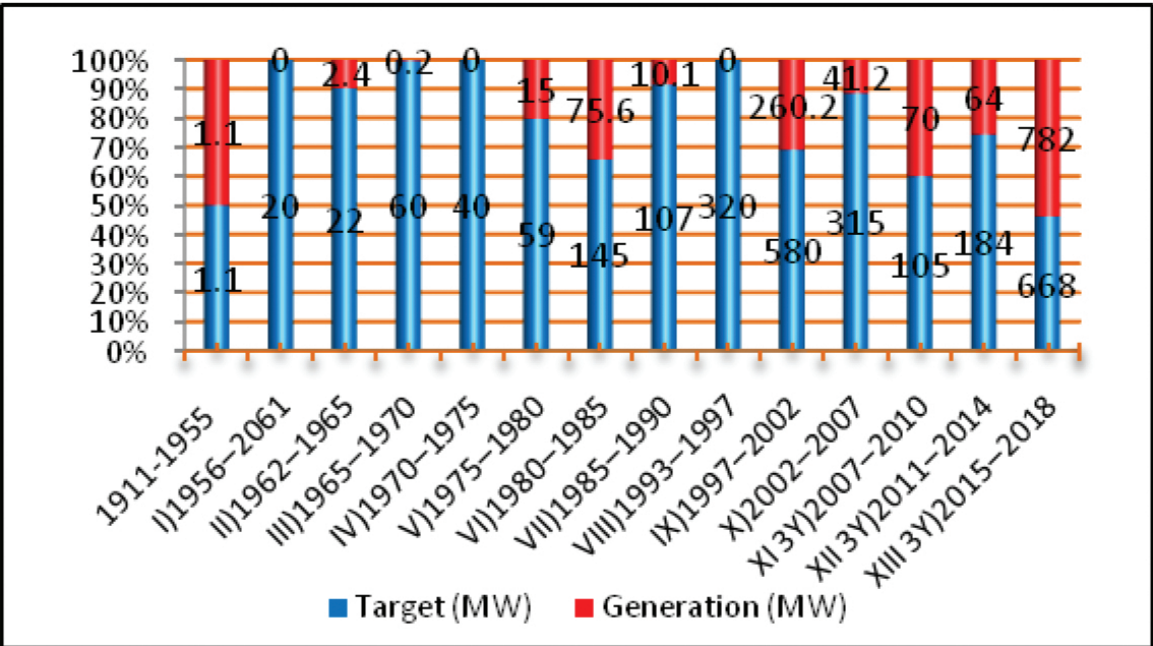


Figure 2. Periodic development of hydropower in Nepal (1911–2016).

3.1. Contribution of hydropower to reduce GHG emissions

The electricity generation and supply become even more important in combination with increasing shares of renewable energies with the low-carbon future envisioned in the Paris agreement. The climate meeting held in Paris in December 2015 (COP21) has superseded global efforts toward embarking upon climate change as the largest source of greenhouse-gas (GHG) emission from energy sector and CC conference (7-18 Nov. 2016, Marrakech, Morocco)

Conference of the Parties (COP 22), agenda for sustainable development goals to reduce greenhouse gas emissions and foster adaptation efforts. The climate leaders of 150 countries representing 90% of global economic activity and 90% of energy-related GHG emissions have submitted a commitment to reduce emissions. The measures submitted by 40% were related to targeting increased renewable energy and one-third submitted suggested improvised energy efficiency [25]. The G7 countries committed in their Declaration on Climate Change to strive “for a transformation of the energy sectors by 2050” and to “accelerate access to renewable energy in Africa and developing countries in other regions”¹.

Nepal is a country with least 0.027% of the total global GHG emissions. The total GHG emission recorded in 2008 was 30,011 CO₂-eq Gt, which was found to be increased from 124,541 CO₂-eq Gt GHG emissions in 2000. Considering the country as a party of United Nations Framework Convention on Climate Change (UNFCCC), Nepal limits temperature below 2°C leading to 1.5°C above preindustrial levels. According to the Economic Assessment study of climate change in 2013, the direct cost of current climate variability and extreme events in key sectors agriculture, hydropower, and water-induced disasters has estimated which is equivalent to 1.5–2% of current GDP/year (approximately USD 270–360 million/year in 2013 prices). The model projected for hydropower in lower dry season flows leads lower energy availability, while 2800 MW energy production by 2050 estimated cost will increase by USD 2.6 billion (present value). The economic costs of climate change in hydropower, agriculture, and water-induced disasters could be 2–3% of current GDP/year by midcentury. Thus, the generation of renewable energy like hydropower may reduce the emission trend of the GHG. As suggested in Ref. [25] some areas of Nepal are highly vulnerable in terms of landslide, GLOF and flooding events which can be predict and mitigated through climate resilience strategies and adaptation.

4. Policy and legal instruments in hydropower sector

Nepal’s liberal foreign investment policy attracted donor’s assistance in hydropower sector since the 1980s. Among the areas of investment in industry manufacturing, services, tourism, construction, agriculture, minerals, and energy, hydropower sector has a widespread investment opportunity due to liberal policy and environmental friendly enacted legal instruments. The government has prioritized the hydropower sector for foreign and domestic investment. As a result, the hydropower sector has received 46% of total Foreign Direct Investment (FDI) in Nepal, investing commitment for Rs 87.56 billion, out of the total FDI commitment of Rs 190 billion received by the end of 9 month in 2016. The Constitution of the Kingdom of Nepal 2015 (2072 BS) has emphasized the development of energy and protection of natural resources. Nepal is governed as per the new Constitution of Nepal, which came into effect on Sept 20, 2015, replacing the Interim Constitution of 2007.

¹ The 21st annual session of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC). International energy efficiency initiatives were undertaken during 2015 by several United Nations (UN) Regional Commissions, the UN Development Programme, the Global Environment Facility (GEF), the World Bank, the IEA, the EU-GCC Clean Energy Network and the Green Climate Fund of the UN Framework Convention on Climate Change (UNFCCC).

The prevailing policies, acts, and regulations are: Hydropower Development Policy 1992, Water Resources Act 1992, and Electricity Act 1992. For management and development of electricity services, Electricity Act, 1992, Electricity Rules, 1993, and Electricity Tariff Fixation Rules, 1993 are the major legal regimes. The major objectives of the Hydropower Development Policy 1992 were to involve private investment in hydropower generation: in order to fulfill these objectives, concept of BOOT (Build, Operate, Own, and Transfer) in developing hydro projects were introduced. The Hydropower Development Policy 1992, supported by the Electricity Act, 1992, provides incentives to develop hydropower in Nepal.

Similarly, Foreign Investment and One Industrial Policy, 1992, Industrial Enterprises Act 1992, Foreign Investment and Technology Transfer Act, 1992, Environment Protection Act and Environment Protection Regulation, 1997 were enacted to strengthen the sector together with protecting the natural environment. The promulgated Ninth Five-Year Plan (1997–2002) of the government had included institutional reforms to attract private sector in power generation and distribution and various programs such as generation and supply of electricity, power transmission, system strengthening, feasibility study, and design for rural electrification. Likewise, Tenth Five-Year Plan Period (2002–2007) emphasized small, medium, large, and reservoir types of hydropower construction and formulated Water Resources Strategy, 2002 and National Water Plan, 2005. The plan intended to promote integrated development of water resources involving private and public sectors with emphasis on rural electrification and control of unauthorized leakage of electricity. The second Three-Year Plan (2010/2011–2012/2013 (2067/2068–2069/2070) has given special encouragement to not only public sectors but also for private sectors with public-private partnership aspects. Considering the existing legal regime, the total 733.557 MW hydropower has produced up to the year 2014/2015 including 255.647 MW from the private sector. There are 83 projects equivalent to 1521.28 MW installed capacity that are in the construction phase and 33 HEP with 532.542 MW installed capacity that are in different development phases.

Nepal's concern toward conservation and sustainable economic development has signatory of more than 20 international treaty and conventions such as Biological Diversity (CBD) and UN Framework Convention on Climate Change (UNFCCC) in 1992, UN Convention on Combating Desertification (UNCCD), 1994 and Kyoto Protocol in 1997. The climate change issues raised in Nepal formed Climate Change Council in 1999 and adopted Climate Change Policy in 2011 with its main aim to improve socioeconomic development with improvement of livelihoods by mitigating and adapting adverse impacts and adoption of low-carbon emission-based development.

Nepal's Climate Change Policy (2011) has envisaged protection of environment and sustainable human development by promoting the use of clean energy, reducing GHG emissions, enhancing the climate adaptation, and resilience capacity of local communities. The emissions of carbon threaten basic elements of society like water, food production, health, and the environment imposing a huge social cost as anywhere from \$8 per ton to as high as \$100 per ton of CO₂. Fossil fuel combustion for transportation and electricity generation are the main source of CO₂ generation, contributing more than 50% of the emissions, and generation of electricity with thermal power plants contributes 66% the world's electric generation capacity.

However, the hydropower represents only 20% of the electricity generation capacity of the world, which emits 35–70 times less GHGs per TWh than thermal power plants [26]. To achieve energy efficiency and energy security, the hydropower projects aim to access affordable and reliable energy service and reduce high carbon emission replacing petroleum products to the extent possible in transport, industry, and household sectors.

The main objective of Thirteenth Three-Year Plan (2013–2016) on Water Sector [12] is to upgrade living standards of the people with their socioeconomic development and reduction of poverty line as below 18% [12]. The plan emphasized to upgrade Nepal accessing people toward drinking water from 85 to 96.25%; sanitation from 62 to 90.5%, and grid-connected electricity generation from 758 to 1426 MW accessing electricity from 67.3 to 87% and ranked Nepal as a developed country by 2022.

5. Impacts and implications

5.1. Adverse impacts of hydropower development

Although hydropower is known as clean energy, it has many associated environmental impacts and implications, like first-order abiotic and biotic impact occurs simultaneously with dam closure and influence within the downstream river and connected ecosystems (changes in flow, water quality, and sediment load). The second-order modified the first-order impacts changing channel with downstream ecosystem and primary productivity in long terms. The third-order impacts are biotic, changes resulting from the integrated effect of all the first- and second-order changes, including the impact on species close to the top of the food chain changes in invertebrate communities and fish, birds, and mammals [27]. Similarly, impacts of hydropower development defined as serious and significantly leading to increasing poverty, social dislocation, and loss of terrestrial and aquatic biodiversity especially dealing to fish resources [27–31].

The river basins in Nepal have extensive pressure due to developmental and demographic growth creating consequent adverse effects on aquatic biodiversity especially the native fish fauna. The greatest threat occurs to the migratory fishes, as their migratory path is obstructed by hydropower structures and fish species are depleting [32–35]. The hydropower generation changes the river system by obstructing habitat ground of the fish species. Fish migration from the downstream barrier to the upstream barrier created dam and passing through turbines, spillways, or in the diversion subjected to injury by physical contact, pressure change, shears force, or eddies. The nature of the river bottom will change, the water quality may also change [36, 37]. A study on the impact of dams on different rivers in Nepal indicated its potential to alter the health and integrity of the rivers with effects being more serious downstream [38].

Adverse impacts of hydropower projects poses project-specific impacts related to project design, size, types, location including physical, biological socioeconomic, and cultural environmental characteristics [15]. There may have fewer adverse impacts on RoR types of projects with high head and small reservoirs with much smaller foot print than the large

reservoirs. However, additional benefits found some large reservoirs like flood control, irrigation, aquaculture, and recreation/tourism opportunities [39–44]. Similarly, summarizing the previous studies and research findings [10] has observed and analyzed key environmental challenges and impacts of the hydropower sector in Nepal such as landslide, sediments load, loss of biodiversity, declining fish species, alternation of hydrological pattern, change in river morphology, water pollution, and other associate social impacts.

The detailed study of Bhote Koshi HEP reveals that the project impact on forests of project and the influenced area cannot recover the natural condition of the local environment but the effective implementation of EIA mitigation measures could reduce the impacts [45]. The identified monitoring indicators and parameters during construction, operation, and implementation phases of upper Bhote Koshi regarding: (i) physical-air quality, noise level, vibration, water quality, erosion and stability of slope, (ii) biological-forest and vegetation, wildlife, and biodiversity and fisheries, and (iii) socioeconomic environment, all these parameters are limited on natural disasters like, flooding, landslide, erosion, and possible risk of GLOF only.

5.2. Climate change and vulnerability

Nepal is one of the most vulnerable countries to climate change, water-induced disasters and hydrometeorological extreme events such as droughts, storms, floods, inundation, landslides, debris flow, soil erosion, and avalanches [46]. According to previous report, 22 districts are highly vulnerable in terms of landslide-prone areas, 12 districts to GLOF, and 9 for flooding. National communication report 2015 described an increasing trend of climate change from the energy sector. In the case of hydropower, the model projected lower dry season flows and thus lower energy availability while 2800 MW energy production by 2050 with an increased cost of USD 2.6 billion (present value) was estimated. The economic costs of climate change in hydropower, agriculture, and water-induced disasters could be 2–3% of current GDP/year by midcentury.

Internationally determined contributions [47], acknowledge that the high vulnerability of Nepal's energy sector to climate change, and identified this as a crucial dimension of the country's overall vulnerability to climate change, and as a critical threat to the economic well-being, livelihoods, and energy security of the Nepalese population. Nepal's hydropower plants and indeed its entire energy system are already vulnerable to extreme weather events, as made clear by the NEA/WECEs Energy Status Reports. However, for implementation of INDC, Nepal will contribute to global efforts to reduce GHG emissions for life-support systems adapting and build climate resilience development to mitigate climate change impacts. The renewable energy demand needs to be integrated in other sectoral policies [48].

Nepal's mountainous and challenging topography and socioeconomic conditions (ranks 145 on the Human Development Index, nearly one-fourth of its population live below poverty line) make it a highly vulnerable country to climate change. Nepal has experienced changes in temperature and mean precipitation. The country, with the exception of some isolated pockets, has become warmer. Data on trends from 1975 to 2005 showed 0.06°C increase in temperature annually whereas mean rainfall has significantly decreased to an average of 3.7 mm (–3.2%) per month per decade. Under various climate change scenarios, mean annual temperatures

are projected to increase between 1.3 and 3.8°C by the 2060s and 1.8 and 5.8°C by the 2090s. Annual precipitation is projected to reduce in a range of 10–20% across the country.

These vulnerabilities are being exacerbated by climate change. As detailed in Nepal's Second National Communication [49], Nepal's hydropower plants are highly vulnerable to the projected impacts of climate change as they depend upon river basins fed by glacial meltwater and snowmelt. The challenging environment in Nepal, Himalayan glaciers are receding faster than the other glaciers in the world [50]. The total 3252 glaciers in Nepal covering a total area of 5312 km² studied in 2001, whereas 3808 glaciers covering an area of 4212 km² were reported in the study of 2010 [51]. Most climate models predict significant changes in the dynamics of mountain glaciers, snowmelt, and precipitation as the climate warms. The International Commission on Large Dams [52] has already emphasized the urgent need to adapt older dams to cope with the impacts of climate change. At the same time, Nepal's poverty reduction strategy emphasizes the importance of increasing availability of affordable energy and using Nepal's abundant hydropower resources to promote economic growth and development.

5.3. Natural disaster

Nepal (relief) Natural Calamities Act, 1992, concerning most devastating disasters, earthquakes since 1934, 1980, 1988–2015 and summer flooding events of 1993, 2008, 2013, and 2014. The another great event of 7.8 magnitude earthquake struck Nepal on 25 April 2015 (11:56 am local time) epicenter in Barpak Village of Gorkha district, 81 km northwest from the capital city of Kathmandu [53]. The earthquake directly affected 14 districts with human and livestock casualties, infrastructure, and physical property. The Gorkha earthquake 2015, damaged buildings and infrastructures like road, hydropower projects, residential, and school buildings. Burial of the entire Langtang village, blocking of Kaligandaki river, damages to hydropower projects and damages to Araniko and Rasuwagadhi highways connecting to China were the major noticeable events due to the earthquake-induced landslide.



Figure 3. Flooding washed way Bhotekoshi Hydropower Project, July 6, 2016 4:11.

In addition, numerous stretches of the feeder roads and trails were also damaged [54]. Bhotekoshi hydropower project was affected by earthquake-induced landslides damaging penstock

stock and powerhouse sites destruction. Similarly, landslide damaged penstock alignment of Sanima, powerhouse site of Aankhu Khola, Chaku Khola and middle Bhote Koshi hydropower projects. A year later of earthquakes struck, landslide dam burst in Tibet has caused heavy destruction at downstream sections of Bhotekoshi river in July 2016 (**Figure 3**).

Similarly, the Jure landslide occurred in August 2014 brought down a whole mountainside and blocked the river. Landslides that hit the entire Jure bazaar in Mankha of Sindhupalchok, killing an unknown number of people, went on to block the course of Sunkoshi river. The river blockage, on the other hand, has imposed a threat of outburst floods, threatening thousands of people living downstream, and inundated at upstream. Nearly 10% of the nation's hydropower capacity, some 67 MW, was severed by the landslide, submerging a 5 MW power plant and disconnection of the power supply with 45 MW Bhotekosi hydropower and 10 MW Sunkosi hydropower and washed out over 400 houses, killing over 200 people.

5.3.1. Glacial lake outburst floods (GLOF)

In region of the great Himalaya, 17% of the area covered by glacier and ice cover and nearly 113,000 km², the total area covered by glaciers and permafrost outside the polar region. The Himalayan region has 35,000 km² of glaciers, and a total of 3700 km³ ice reserve. The Himalayan region is the source of nine largest rivers in Asia where over 1.3 billion people lived. The warming in Nepal and Tibet increased progressively within a range of 0.2–0.6°C per decade between 1951 and 2001, particularly during autumn and winter. Over the past 30 years, the length of the growing season has increased by almost 15 days. The Himalayas glacier melt has increased the frequency and intensity of risks like floods, avalanches, failure of moraine-dammed lakes, and water regime affects.



Figure 4. Impacts of GLOF of hydropower UBHP (45 MW), July 2016.

Thus, the breaks of dams devastating debris flows occur, internationally called GLOFs. As several downstream hydropower are in risk in Nepal, recently July 16, 2016 UBHP (36 MW) was destroyed by GLOF generated from Nyalm Tibet (**Figure 4**). Previous recorded events of NEA, Namche HEP swept away in 1985 through Dig Tsho GLOF, and huge flood struck on 27 August 2008 in 4 MW Khudi HEP.

5.4. Policy level implications in hydropower sector

The concerned policies like Water Resources Act, 2049, Electricity Act, 2049, Water Resource Regulation, 2050, Electricity Regulation, 2050 in the hydropower sector have not described threshold criteria in terms of environmental sensitivity. Previously, 5-MW threshold criteria of EIA guideline 1993 repeatedly addressed in the Environment Protection Act and Rules, 1997 for the environmental assessment process. This criterion had raised issues in a licensing process and well as environmental assessment process of hydropower generation. The Water Resources Development Policy, 2001, has a provision to promote an integration of environmental aspects during the development of water resource sector [55]. The policy urges to ensure minimum release of 10% discharge or more as recommended by the EIA study during the construction and operation of hydropower projects, and encourages the private developers to acquire necessary land for the project by themselves. These criteria are not applicable for every project considering the size, location, and sensitivity. Owing to the policy, electricity supply is limited to 43.6% for urban population (2009) and only 8% access in rural areas. As a result, Nepal has limited access and low-level electricity consumption among other developing countries [23]. The policy level document of the sector has not defined high dam impacts and mitigation measures. All policy is conventional and needs to be reformulated in the present context.

5.4.1. Policy level implications in EIA process

In hydropower projects, Ministry of Water Resource (MOWR) is responsible for compliance monitoring and role of environmental assessment facilitator for sectoral agencies. The Ministry has a lead role with project proponent and reviewer's role for monitoring of compliance and monitoring from the Ministry of Environment as an EIA approval agency. The Ministry of Environment (MoE), a leading agency of all EIA approval process, monitoring is inactive due to lack of trained human resources as well as guided policy. The major policy level implications regarding protected species of government, CITES Appendices and IUCN red list category, maintaining 40% forest area, downstream release of 10% water in HEPs, assessed impacts were found significant even if a single tree to be felled during project implementation. Consequently, downstream release of 10% water in hydropower projects and significant impact of tree felled has observed policy level constraints. Similarly, it has assessed that the provisions related to prediction, monitoring, and evaluation of impacts has not fully considered in EIA studies and its implementation as per EPR 1997.

EIA reports generally recommended mitigation measures for adverse impacts of the commenced power projects but trend remains limited to implementation of major issues and impacts. Not enough considerations have been made in the issue of ambient air pollution,

noise, and vibration control specifications as well as protected flora and fauna Contractor's responsibility for arranging to provide awareness for environmental protection is not addressed in the tender document. Some of the mitigation measures recommended in EIA report were seen irrelevant during operation as serious shortcoming in EIA qualitative data (e.g., species lists, distribution, and habitats) identified previously in some studies [56–59]. To produce cheaper hydro energy, national capabilities need to be strengthened, although there are some legal issues for the development of hydropower such as nonspecificity of water rights and ownership; lack of subordinate enabling legislation; lack of harmony among related legislation; and lack of adequate legal provisions to encourage private sector participation in multipurpose projects [60].

5.5. Challenges and opportunities

The major thrust for hydropower development in Nepal is the financial investment and risk of natural catastrophe. On the other hand, the environmental and social impacts are linked to the development of hydropower projects which obey misrepresented and this delays the process, or in some cases stops the development of hydropower project. The World Bank had withdrawn the Arun III Project in 1995 in Nepal [31], concerning environmental and social impacts of this project and the government instability might be the reason behind it. In 2007, NEA sold 40.7% of its electricity to domestic users, 38% to industries, 6.6% to commercial and rest to noncommercial including the agricultural sector at 79 kWh [61]. Nepal's per capita consumption of electricity is one of the lowest in the world; however, some countries like Singapore has the per capita 6500 kWh consumption. Nepal's dependence on technical for planning, designing, and constructing water development projects and financial support for large-scale projects slow down the hydropower development process. The Power Investment Summit organized by the Energy Development Council (EDC) 2016 concluded that Nepal requires \$20 billion to develop 10,000 MW on grid hydropower projects in the next 10 years. Investment of \$5 billion needed for high-voltage transmission line projects to be completed within 2035. The investment opportunities on Budhigandaki 1200 MW, Nalsingad 410 MW, Tamor 762 MW, Andhikhola 180 MW, Tamakoshi V 87 MW, Upper Tamor 415 MW, Tamakoshi III 650 MW, and Thuli Bheri 530 MW projects have been identified issuing a statement by the EDC.

Landslide dam outburst floods (LDOFs) is one of the major challenges for hydropower development in Nepal due to its rugged topography, susceptible to landslides, very high relief, and intense precipitation during the monsoon period, for example, UBHEP event of July 2016 learnt more about it. As the glacier melt, water volume initially increases with an increase of temperature and hydropower potential generally increases accordingly, as it largely depends on the lean season flows. Nepal's hydropower generation generally follows the pattern of dry season flows [62]. Over 90% of Nepal's existing hydropower plants are the runoff river type, which are generally designed based on the dry season flows. These power plants have been already facing the problem of water shortages during dry seasons and generating only about 30% of the total installed capacity in dry months. The problem will be further exacerbated during dry season by the reduced snow and glacier-melt contribution in the future [63].

However, there is a new opportunity for hydropower from climate change is to increase-installed capacity because increasing precipitation and storage projects help to adapt climate change for local people [64].

The flooding events like GLOFs, LDOFs, and flash floods increase sediment or debris flow on the reservoir that may loss production capacity. In July 1993, Kulekhani project had turn out such event causing high sediment and debris inflow to the reservoir because of flood. Similarly, in 2014, landslide occurred during monsoon which badly hit United Modi Project 10 MW, and damaged the concrete cover slab of hundreds of meters of the headrace tunnel and canal covered by debris. Out of the total available energy in 2012, only less than 1% was from the thermal sources and about 80% was from domestic hydropower plants [65]. Any decrease in the river flows during dry season due to the decreased glacier ice reserve and decreased flows of the rain-fed rivers as projected will further deteriorate the electricity generation.

Nepal's energy market is dependent on hydropower generation. The power demand for Nepal was 470 MW in 2002–2003 with available 2261 GWh, out of which 2107 GWh energy system within NEA was met by hydropower generation (93%). Despite having a potential to generate 43,000 MW of electricity, Nepal's installed hydropower capacity is just 787 MW, which is less than half of the demand. Even at a high growth scenario of about 12% per annum, peak power demand will reach only 3400 MW and energy requirement 16,000 GWh in 2020. Thus, even in the foreseeable future Nepal's electricity needs will still be a small percentage of its realizable hydropower potential. Thus, in order for Nepal to exploit its hydropower potential in a substantive way, it has to look for an export market where there is a demand for such power (Nepal's Electricity Act, 1992, provides for export of electricity generated by a developer to foreign country by entering into an agreement with the government. The developer will have to pay export duty as determined in such agreement).

6. Mitigation and adaptation

Nepal has planned to produce 12,000 MW clean energy by 2030 including 4000 MW hydro-electricity by 2020, 2100 MW solar energy, 220 MW bioenergy by 2030, and 50 MW of electricity from small and micro-hydropower plants. Nepal government has a strategy to maintain 40% of the total forest area of the country promoting conservation of biodiversity, resilience infrastructure, a forestation in public, and private lands. The ecosystem of ecoregions of the country supports to be managed endorsing sustainable management of forests, enhance capacity of local communities' adaptation and resilience, widen carbon storage through sustainable forest management, and reduce carbon emissions.

The conventional or ongoing approach to determine the dam and reservoirs capacity during planning and design phases on the basis of limited data and estimation of sediment discharge could be improved by considering seismic design through ICOLD Bulletin 148 (2010), guidelines for the study of hydropower projects [66]. Likewise, GLOF risks are difficult to predict but proper assessment of glacial hazards in upstream catchments, reviewed, and monitored regularly, preferably every 5 years may help for preparedness and appropriate

strategies for mitigation of the probable risk [67]. For such events, Nepal has adopted national policies, strategies, and program such as Sustainable Agenda for Nepal (2003), Water Resources Strategy (2002), National Water Plan (2005), and Disaster Risk Reduction Strategy (2009) which can be the best mitigation measures for HEP development.

To evaluate possible risks or failure and downstream hazards all actions such as early warning system, emergency action planning, dam-break hazard analyses, inundation mapping, dam-break flood analyses, and dam-break mechanism practices for emergency action planning are necessary to be taken or embarked. The key contribution of afforestation activities in tropical zones avoiding deforestation, or REDD (Reducing Emissions from Deforestation and Forest Degradation), Kyoto Protocol, Clean Development Mechanism (CDM) negotiations are underway for the future international climate agreement. Similarly, internally emerged effective and environmentally, economically and socially adaptive ecosystem-based approach can be resilient the hydropower infrastructure and reservoirs to cope with the impact of climate change. The storage hydropower brings climate adaptation services like flood protection, source of water supply for agricultural, industrial, urban, and/or environmental purposes. Nepal's sustainable goal 2016–2030 emphasized major objectives to access quantity and quality-based electricity supply with efficiency, safety and convenience of household energy, and promotion of hydropower potential as clean energy in the South Asian region [68]. Thus, there is a great need to protect the ecosystem together with the hydropower development by improving resilient hydropower infrastructure through good planning, design and sitting; construction; operation and maintenance, contingency planning, and restoring ecofriendly environment.

The benefit of hydropower can be analyzed, the example of a case study that the Upper Bhote Koshi plant (45 MW) annual electricity output with 70% Plant Capacity Factor would be 275,940 MWh/year. To determine expected project emissions of hydropower annual CO₂ emissions (tons CO₂) = zero project emissions. The annual baseline emissions reduction for UBHEP only will be 160,092 tons CO₂/year. Since 2001–2016, Bhote Koshi HEP alone has reduced approx. 2,49,1380 tonsCO₂.

7. Conclusion

The global energy agenda for the seventh successive year in 2016 renewable energies is the high impact issue for the feature, with a strong perception to reduced uncertainty, as a top action for priority agenda in the energy sector, to build on the importance of developments around both climatic framework and innovation. The countries determinant commitment in COP21, toward an increase in the anticipation for further scaling up of renewable energies, reinforcing the reduced level of uncertainty as large hydro is understandably an issue closely aligned to localized resource availability and sustainable development 2030s goals for benefiting and adapting climate change of COP 22s efforts. Hydropower development is the top priority action of global energy leaders such as Latin America, followed in priority for those in Asia and Africa who perceive the issue with similar low uncertainty but a relatively

low degree of impact. All countries have energy efficiency priority in policy objectives bearing in mind its multiples benefits including prominent role on climate change issues/GHG reductions. In this context, Asia has estimated the largest remaining unutilized potential of hydropower at 7195 TWh/year, making it the likely leading market for future development [69] and support to reduce global GHG emission in the near future.

The hydropower potential in Nepal depends on the 6000 or more rivers flowing from mountains to hills and plains, although Nepal is divided into five geographic regions namely Terai plain, Siwalik Hills, Middle Mountains, High Mountains, and the High Himalayas. The world's water coverage of 97% seawater and 3% fresh water, Nepal constitutes nearly 5000 lakes; 1380 reservoirs; and 5183 village ponds including 3808 glaciers with a total area of 4212 km², and 1466 glacial lakes with an area of 64.75 km². Among these glacial lakes, 20 lakes were identified as a potential risk of glacial lake outburst floods [70]. Despite the natural beauty of Nepal with its unique topography, ecological regions, geography, and enormous source of water potential, Nepal is the poorest countries in the world wherever electricity infrastructure is heavily reliant for hydroelectricity power generation.

Despite the high potential of hydropower potential, Nepal's low economy and slow GDP growth rate in combination with environmental and socioeconomic constraints, effective implementation of existing policy and political stability may support to reach the sustainable development goals of the county. Nepal however ratified the UNFCCC, the Convention to Combat Desertification (UNCCD), and the Convention on Biodiversity (UNCBD), the most critical impacts of climate change consisting water resources and hydropower generation, stemming from glacier retreat, expansion of glacial lakes, and changes in seasonality and intensity of precipitation through the grid and off grid system. The projected climate change scenarios for Nepal average mean temperature will increase by 1.2 and 3°C as projected by 2050 and 2100. This trend is significantly dangerous for glacier retreat and glacial lakes expansion, making them more prone to GLOF. The GLOFs significant impacts on hydropower, rural livelihoods, and agriculture and storages dams anticipated a climate change impacts which poses environmental conflicts for sustainable hydropower development.

The national and international norms, policies, laws, and regulations for maintenance of ecological integrity are generally not fulfilled as per the case study of UBHP. Maintenance of 40% forest area, downstream release of 10% water, and compensation even for singletree are the significant constraints short out in implementing-related policies. The benefits of hydropower development should be considered with analysis of cost benefit, technical accuracy, and scientific structural design, implementation of relevant policy and legal instruments, strong implementation of EIA mitigation measures might make hydropower sustainable clean energy reducing global warming, and dependency on fossil fuel. The impacts on physical receptors especially downstream flow and change in river morphology have generated major concern as they remain as cumulative impacts. The fluctuation of minimum downstream release was found as the major cause for declining fish diversity. More anthropogenic disturbances and project structures were found creating impact on extinction of wildlife and protected species like birds and mammals. Furthermore, hydropower development has negative environmental and social consequences, although it does not emit

air pollution or greenhouse gas emissions. Since 1970, global hydroelectric capacity doubled and dam blocking of rivers degrading water quality, disturbance of aquatic and riparian habitat, migratory fish route blockage, economic impacts on fishery, and displacement of local communities.

Author details

Ramesh Prasad Bhatt

Address all correspondence to: drrameshbhatta@gmail.com

Institute of Ecology and Environment, Budhanilkhantha, Kathmandu, Nepal

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