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CLIMATE CHANGE IMPACTS ON HIMALAYAN GLACIERS AND IMPLICATIONS ON ENERGY SECURITY OF THE COUNTRY

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CLIMATE CHANGE IMPACTS ON HIMALAYAN GLACIERS AND IMPLICATIONS ON ENERGY SECURITY OF THE COUNTRY

Abstract: *Climate change has strong influence on the precipitation over Himalayas as well as melting response of glaciers/ snow cover in Himalayas. This in turn affects the runoff pattern of rivers draining from the glaciated catchments of Himalayas. Three major river catchments along with their several tributaries originating from Indian as well as Nepal part of Himalayas, receive significant contribution from Himalayan cryosphere, especially during the non-rainfall lean period of the year.*

These rivers support the life and livelihood of more than 500 million people living downstream in Indo-Gangetic plains, but also support several industries located in these plains. Simultaneously, Himalayan rivers are also responsible for ensuring energy security of the country, due to their role in supporting the production of both hydro as well as thermal electricity through dams/ power plants located in the Indo-gangetic plains. It is estimated that almost 1/3rd of country's electricity production capacity is located in these plains, and any variability in flow pattern of Himalayan rivers can have far-reaching consequences for energy security of the country.

This study tries to correlate the impacts of climate change on the energy security of the country by studying the water footprints of energy production in the country and available literature on the variability of meltwater in the Himalayan rivers. The study recommends that focus of policy making on renewable energy should have equal impetus on reducing the water footprints of electricity production, and river valley specific plans are required to generate adaptation plans for energy projects in the country.

Water dependent energy scenarios

Indian energy system is dependent on a mix of conventional fuels such as coal, oil, gas, synthetic fuels and non-conventional sources such as biomass, hydropower, nuclear, solar, wind, and geothermal. However, conventional fuels still dominate the electricity production as well as transportation sector, in both present as well as near future perspectives. Coal based thermal power plants are the dominant player in Indian Power sector, constituting 54.3% of total installed capacity of 360 Gigawatt (GW) electricity production, as on 31th July 2019. Production of coal in the country has increased by 7.5 times and production of electricity has increased by 13 times since 1970-71. Furthermore, NITI Aayog projects that the total installed capacity for electricity generation in the country will range from 300-700 GW by 2047 under different policy initiative scenarios. Considering the practicality of implementation, even with best of efforts to diversify the fuel and technology mix in the power generation sector, India would continue to rely heavily on coal based electricity generation, accounting for atleast 50-60% of the total capacity.

Also, India's energy security is dependent on production of crude oil as well as refining of imported crude oil. India produced 36 Million Tonnes (MT) of crude oil and imported 214 MT of crude oil in 2016-17. As a result, India produced 242.7 MT of petroleum products from refineries and fractionators. Total installed refining capacity in the country has almost doubled since 2000 from 112.04 MT to 234 MT in 2017. As such, the consumption of conventional energy resources has almost tripled since 1990-91.

Conventional Fuels and Water

Water is needed throughout the energy supply chain, sometimes as a direct input as in the case of hydropower or geothermal energy, as a coolant in thermal power plants or more often for the extraction and processing of energy fuels. Thus, conventional fuels used both for electricity production as well as for transport requirement, depend heavily on usage of water.

Water As coolant

The two widely implemented types of cooling for power production are once-through cooling and closed-loop cooling; the minor type is termed dry cooling. For once-through cooling, river or lake water is passed through a heat exchanger to condense the steam. The exiting condenser water is pumped back through the cycle and the river water is returned to the stream. Although the consumptive water use is minimal, the amount of water

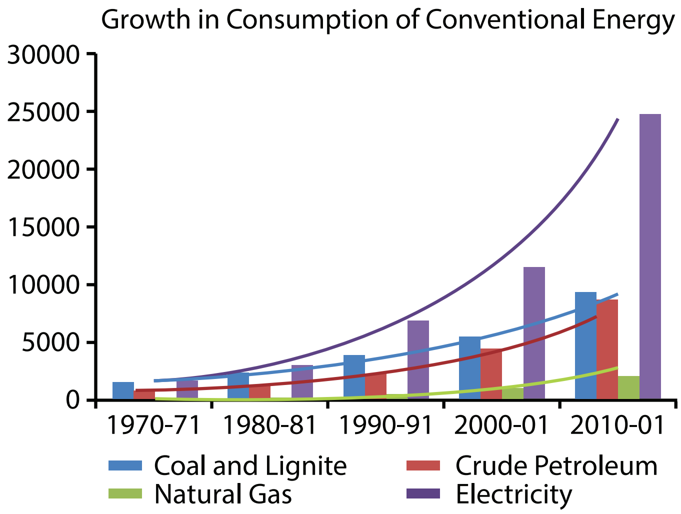

Figure 1: Trends in Consumption of Conventional

Sources of Energy in India (Data Source: Energy Statistics 2013)

withdrawn from the river is significant. A closed-loop cooling system consumes much more water than once-through types because the entire energy exchange is through evaporation of water - a consumptive use. Dry cooling typically requires a fan to aid in heat removal. The advantage to dry cooling is the water withdrawals and consumptions are zero (Torcellini et.al., 2003), but dry cooling systems result in reduced power output and increased heat rate (lower efficiency) of the unit besides higher capital cost.

It is estimated that water withdrawal for electricity generation for 'once through cooling' technology range from 100-180 L/kWh for coal, 80-140 L/kWh for gas/oil, and 140-200 L/kWh for nuclear power plants. However, for 'closed loop cooling' technology, water withdrawal range from 2-4 L/kWh irrespective of fuel used (EPRI, 2008). Thus, water withdrawal from the freshwater source has reduced considerably in recent years, but consumptive use has increased which is proportional to the number of hours, a plant operates. The consumptive water requirement for coal based plants with cooling tower in India is about 3.5 – 5 L/ kWh (CEA, 2012). As such, thermal power plants with total installed capacity of 190.3 GW in the country are consuming atleast 705 million litres of water every hour.

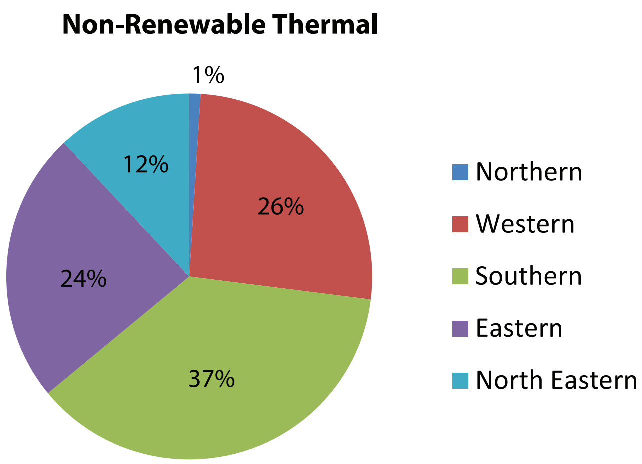

Figure 2: Regional distribution of non-renewable thermal electricity production in India

In India, the share of nuclear power is 1.95% of the total installed capacity. With exponential growth in energy demand coupled with a finite availability of coal, oil, and gas; there is a renewed emphasis on nuclear energy. Nuclear power plants consume more water as compared to coal based thermal power plants (NEI, 2012). While new plants are being constructed at coastal locations and are based on desalinated water, still almost 35% of nuclear power is from inland locations.

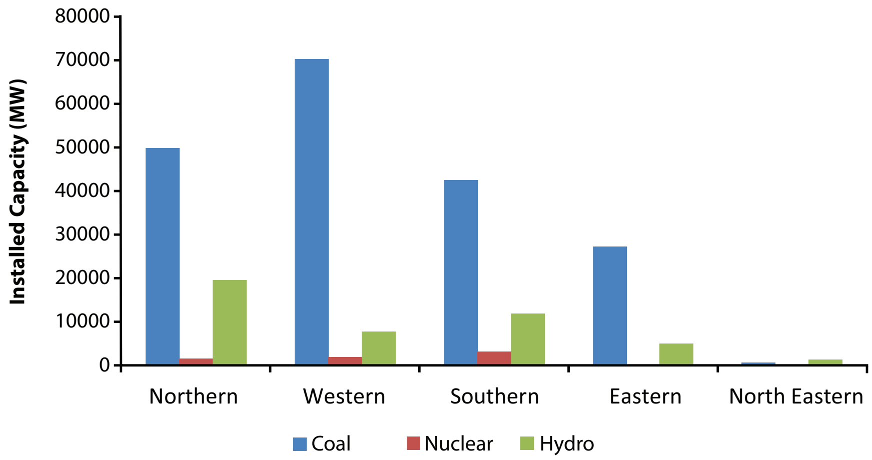

Figure 3: Regional distribution of electricity production (Coal, Nuclear and Hydro) in India

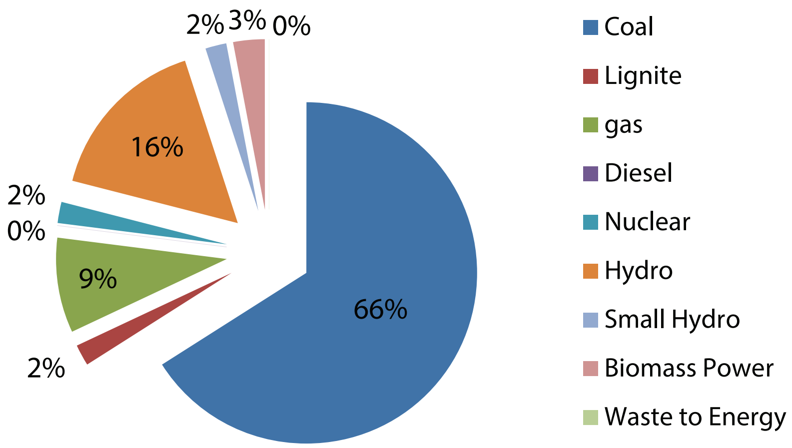

Figure 4: Proportional distribution of electricity production mix in India

83% of total electricity production in the country is based on utilization of water

Water for mining, extraction and refining of conventional fuel

Natural gas extraction is considered water efficient because the withdrawn groundwater (used for gas purification) is mostly re-injected back into the aquifer. Significant quantities of water are being produced in the course of coal seam gas water exploration and production (Penton 2009). There have been reports across the world on aquifer depletion and pollution in areas where coal seam gas wells have been established and also cases on its impact on crops and farm lands. Drilling process for oil extraction requires minimal amounts of water but a large amount of water called produced water is withdrawn with the extracted oil. On average, a barrel of oil brings up about six barrels of produced water. Water is also used during the petroleum refining process such as desalting and alkylation. Refineries use about 1.5 - 1.7 m^3 of water for every metric tonne of product (Sustainability Report 2015-16), which means that India refining nearly 0.64 million metric tonnes of petroleum products per day, consumes about 1 billion litres of water each day.

Non-conventional energy and water

Hydroelectric power generation depends completely on water availability. Water flowing through the turbines and into the river is not considered consumptive because it is still immediately available for other uses. However, the increased surface area of the reservoir, when compared to the free flowing stream, results in additional water evaporation from the surface and it is important to note it as a function of the amount of energy produced. Hydropower projects could alter flow regimes below storage reservoirs or within diverted stream reaches leading to water quality degradation and flooding of terrestrial ecosystems by new impoundments and may get affected by climate change impacts on the hydrological cycle (Curlee and Michael, 2003). Intense flooding can also affect power generation by increasing turbidity levels in intake water. These water events are episodic in nature and their frequency and severity are projected to increase over time. Hydro plants generally have a long life span (around 80 years). As a result, the impacts of climate change may dramatically change local water flows from when they were first studied during project development.

Bioenergy is considered environmentally benign and climate friendly. But bioenergy crops are water intensive and the water foot prints are much higher than that of non- renewable fuels. In the case of biofuels, the crop irrigation water demand for production of biofuels like ethanol from sorghum, sugar cane and cellulose depends on its geographic location, climate, and type of feedstock. Bio-diesel in India is mainly produced from the tree-based oil crop Jatropha. Thus, Major water use for Bioenergy production is for irrigation of crops (Gupta 2002).

Solar energy

India's national solar mission sets an ambitious target of 100 GW of grid connected solar power projects by 2022 to address both the domestic challenge of energy shortages and the global challenge of climate change. For the purpose, the government has set a target of setting atleast 50 solar parks every year, each with a capacity of 500 MW and above. Solar parks with the capacity of 26,500 MW have already been approved, with major parks equivalent to 60% of approved capacity being in the states of Andhra Pradesh, Gujarat and Rajasthan.

A Concentrated Solar Power system consumes about 3.5 m^3/ MWh water for production of electricity, which is equivalent to the conventional coal based thermal power plants. Similarly, water consumption for cleaning of solar panels in PV systems has been estimated as 20-30 m^3/ MW per wash. We estimate that with the complete installation of targeted solar power capacity of 100 GW, water consumption for solar electricity could be more than the water requirement for coal based electricity. As such, electricity produced per unit of water is less for solar power plants as compared to coal power plants.

Table 1: Interconnections of Energy Sector with Water Availability and Quality

Energy Element	Connection to Water Quantity	Connection to Water Quality
Energy Extraction and Production		
Oil and Gas Exploration	Water for drilling, completion, and fracturing	Impact on shallow groundwater quality
Oil and Gas Production	Large volume of produced, impaired water*	Produced water can impact surface and groundwater
Coal and Uranium Mining	Mining operations can generate large quantities of water	Tailings and drainage can impact surface water and ground-water
Electric Power Generation		
Thermo-electric (fossil, biomass, nuclear)	Surface water and ground water for cooling** and scrubbing	Thermal and air emissions impact surface waters and ecology
Hydro-electric	Reservoirs lose large quantities to evaporation	Can impact water temperatures, quality, ecology
Solar PV and Wind	None during operation : water use for panel and blade washing	
Refining and Processing		
Traditional Oil and Gas Refining	Water needed to refine oil and gas	End use can impact water quality
Biofuels and Ethanol	Water for growing and refining	Refinery waste-water treatment
Synfuels and Hydrogen	Water for synthesis or steam reforming	Wastewater treatment

Table 1: Interconnections of Energy Sector with Water Availability and Quality

Energy Element	Connection to Water Quantity	Connection to Water Quality
Energy Transportation and Storage		
Energy Pipelines	Water for hydrostatic testing	Wastewater requires treatment
Coal Slurry Pipelines	Water for slurry transport; water not returned	Final water is poor quality; requires treatment
Barge Transport of Energy	River flows and stages impact fuel delivery	Spills or accidents can impact water quality
Oil and Gas Storage Caverns	Slurry mining of caverns requires large quantities of water	Slurry disposal impact water quality and ecology

**Impaired water may be saline or contain contaminants ** Includes solar and geothermal steam-electric plants; Source: U.S Department of Energy (2006)*

Climate Change, Himalayan Glaciers and Meltwater

Increasing warmth and humidity in the daily weather, erratic behaviour of rainfall patterns, extension of normal winter season, and increasing incidences of flood, drought and cyclones are some of the common observations, reflective of changes in the normal atmospheric circulation and climate change predictions (IPCC 2007).

Almost 7.7% of global glacierised area is present in South Asia (Vaughn et al. 2013) supporting close to 10% of the global population by providing water during the lean season through snow and ice melt from its cryosphere. On a global scale, glacier mass change ranged between 0.38 – 0.6 mm SLE yr-1 during the last decade as estimated by different scientists using different methodologies (Jacob et al. 2012; Chen et al. 2013; Gardener et al. 2013; Schrama et al. 2014; Yi et al. 2015; Dieng et al. 2015; Reager et al. 2016; Rietbroek et al. 2016; Marzeion et al. 2017). Glacier mass loss for the Hindu Kush-Himalayan region during the last decade ranged between -0.14 to -0.21 m.w.e. yr-1 (Kaab et al. 2012; Gardelle et al. 2013), which is considered to be significantly less negative than the estimated global averages for glaciers (Cogley 2009; WGMS 2012).

Glaciers form where snow is deposited during the cold/humid season and does not entirely melt during warm/dry periods. This seasonal snow gradually densifies and transform into perennial *firn* and finally, after the interconnecting air passages between the grains are closed off, into ice (Paterson, 1994). The ice from such accumulation areas then flows under the influence of its own weight and the local slopes down to lower altitudes, where it melts again (ablation areas). Accumulation and ablation areas are separated by equilibrium line, where the balance between gain and loss of mass is exactly zero. Glacier distribution is thus primarily a function of mean annual air temperature and annual precipitation sums modified by the terrain which influences, for example, the amount of incoming net radiation or the accumulation pattern.

Variations in Himalayan Climate

Temperature plays a dominant role in influencing a glacier's sensitivity. Glaciers in Himalayas are under the influence of westerlies, decreasing from west to east, and the influence of Indian and Asian monsoon, decreasing from eastern Himalayas to west (Burbank et al. 2003; Bookhagen and Burbank 2006, 2010). This complex climate diversity results in a varying pattern of glacier response to climate variables across different river basins (Fujita and Nuimura 2011; Scherler et al. 2011; Bolch et al. 2012; Gardelle et al. 2013; Gardner et al. 2013).

Indian Meteorological Department based on data from 1951-2010, has reported a decrease in mean maximum, mean minimum and mean annual temperature for westernmost state of Jammu and Kashmir in Himalayas, while the same parametres have been reported to be showing positive trends for eastern most states of Sikkim and Arunachal Pradesh. Simultaneously, an increase of 2.13 mm yr-1 in rainfall has been reported for western state and a decrease of about 3 mm yr-1 for the eastern states, over the same time period (IMD 2013). This increase or decrease in rainfall has been attributed mainly to increase in winter rainfall over western state and decrease in monsoon rainfall in eastern states.

However, the trend for decrease in temperature is not consistent throughout western Himalaya, with Himachal Pradesh showing much larger increase in mean maximum temperature and decrease in rainfall than the opposite trends observed for Jammu and Kashmir. Thus, the trends related to both temperature and rainfall variations based on observational records are mixed and consequentially the impacts are also varied from basin to basin.

Climate model based projections indicate a warming by 4-5.5 ºC relative to 1971-2000 time period under SRES emission scenarios, with rate of warming being greatest during the winter months (Wiltshire 2014). The warming rate over Himalayan region is reported to be higher than global average of 0.74°C±0.18/100 year (IPCC 2007). Himalayas have warmed by 1.5°C from 1982-2006, at an average rate of 0.06°C yr-1 (Shrestha et al. 2012).The temperature is projected to increase in the range of 0.5°C to 1°C by 2020s and 1°C to 3°C by mid-century (Kulkarni et al. 2013; Wu et al. 2017). However, warming rate is not uniform either spatially or temporally over the Himalayan region (Singh et al. 2015).

Variations in Himalayan Cryosphere

According to Geological Survey of India, there are 9575 glaciers in Indian Himalaya distributed among the three river basins – Indus, Ganga and Brahmaputra. However, more than 90% of Indian glaciers are small to very small in size – being smaller than 5 km in length and smaller than 5 sq km in area. Most of them are even smaller than 1 sq km in area. Only a few glaciers like Siachen, Gangotri and Zemu are bigger than 10 sq km in area.

Himalayan glaciers are considered to be naturally vulnerable due to their geographical setting. These glaciers are located very close to the tropics at low latitudes, they are on the southern facing slopes of the Himalayas and so there is a natural build-up of high heat content in this region and most of the feeding into these glaciers occurs in the summer season. Snow has very little time to get into the ice mass and to add to the ice volume of the glacier. Furthermore, these glaciers are located in the very highly inhabited districts of the Himalayas, so local pollution has also an impact on the overall melt response of these glaciers.

While smaller glaciers have been estimated to exhibit larger manifestations of climate change impacts, larger glaciers are supposed to continue holding ice mass. IPCC (2014) estimates that while smaller glaciers with their Equilibrium Line Altitude (ELA) already above glacier's highest point are bound to disappear, larger glaciers will continue to shrink for next few decades even if the temperature stabilizes in near future. The ELA in western Himalaya is reported to have shifted upward by 300 m in the last 40 years (Kulkarni et al. 2011), while many glaciers in eastern Himalaya, like Pokalde Glacier in Nepal have been reported to be showing a tendency with the ELA reaching above their highest points (for example in 2011–2012) and are expected to disappear in the near future (Wagnon et al. 2013).

Glacier Retreat

Traditionally, retreat of glaciers has been considered as an important indicator of impacts of climate change on glaciers of a region. Glaciers in the Himalayas (India) have been exhibiting a continuous secular retreat since the earliest recording began around the middle of the 19th century (Raina 2009). Recent studies based on satellite imageries also indicate a continuing retreat of glaciers in Himalayas - East Rathong glacier (15.1m yr-1 (1962-2011), (Agrawal and Tayal 2013); Gangotri glacier (19.9± 0.3m yr-1, 1965-2006), (Bhambri et al. 2012); Samudratapu glacier (18.45 m yr-1, 1963-2004), (Shukla et al. 2009); Dokriani glacier (16.6 m yr-1, 1962-1995), (Dobhal et al. 2004). A region wide study conducted on 7% of glaciers distributed across different basins shows retreating pattern for almost 77% of the glaciers, while 7% glaciers show an advancing pattern. Both number of retreating glaciers and the extent of retreat are reported to be highest for western Himalayan glaciers, while the glaciers in an eastern Himalayan basin have shown no or very less retreat as compared to western Himalaya (SAC 2011).

Areal Change

Change in areal extent of glaciers is also used to understand the impacts of climate change. Several studies have reported a net area loss for different Himalayan glaciers over the last 4-5 decades - East Rathong glacier in eastern Himalaya has lost 15% of the glacierised area from 1962-2011 (Agrawal and Tayal 2013), Gangotri glacier (5.67%, 1965-2006), (Haq et al. 2011); Samudratapu glacier (12.45%, 1963-2004), (Shukla et al. 2009); Dokriani glacier (10.25% loss in frontal area, 1962-1995), (Dobhal et al. 2004). Regional study based on satellite images of glaciers in different sub-basins of Himalayas indicate an area loss ranging between 1-14% varying across basins, over a period of 15 years from 1990. While Alaknanda and Spitti sub-basin in central Himalaya lost almost 10% of their glaciated area, glaciers in Bhagirathi sub-basin, also in central Himalayas, show almost no change in their areal extent (SAC 2011).

Mass Balance and Volume Change

Overall mass balance for the 915 km^2 of glaciers surveyed in western Himalaya was found to be −0.7 to −0.85 m.w.e. yr^{-1}, corresponding to a total mass loss of 3.9 km^3 of water in 5 year duration from 1999 to 2004 (Berthier et al. 2007). Over the past 4 decades, Himalayan glaciers are suggested to have lost almost 10% of their glacial mass (Kulkarni and Karyakarte 2014).

Field measurements of specific mass balance over different regions of the Indian Himalayan glaciers show mostly negative mass balance years with a few positive ones during 1974–2012 (Pratap et al. 2016).

Regional Mass Balance Change

On a regional scale, the rate of observed specific mass loss in Himalayas is reported to be significantly lower when compared with the global glacier loss and is three to four times lower than that observed for glaciers in the European Alps (Huss, 2012, Gardelle et al. 2013, Wagnon et al. 2013). Across HKH region, maximum value of mass balance change has been reported for Jammu and Kashmir state by Kaab et al. 2012 (-0.55 ± 0.08 m w.e. yr^{-1}) but Wiltshire, 2014 indicate a gradient from low to high rates of mass loss from west to east.

Thus, higher rates of warming reported by some studies for high altitude of Himalayas and the lower rates of glacier mass loss do not correspond with each other, and add to the uncertainty about understanding of Himalayan glaciers. But the observations suggest that the glaciers in this region are losing mass in long term, and the rate of melting has increased recently. Since most of the glaciers in Himalayas are small to very small in size (<5 km^2), the region is very likely to experience more mass loss in the coming decades despite anomalies at sub-basin scale, influencing the water supply for downstream communities.

Impacts on Runoff Patterns

Almost 800 million people living in Indus, Ganges and Brahmaputra river basins are dependent on Himalayan glaciers (Immerzeel et al. 2010, Kaser et al. 2010). They provide water during the lean summer season when demand is high and precipitation is less. Hydrology of glacierised regions is thermally controlled (Young 1985) and the increasing temperature mostly affect the timing of runoff. Gardelle et al. 2013 reported that glacier mass loss during 1999-2010 contributed 103 m^3s^{-1}, 103 m^3s^{-1} and 147 m^3s^{-1} to the river discharge in Indus, Ganges and Brahmaputra, respectively.

The three great rivers of India – the Indus, the Ganges and the Brahmaputra collectively provide close to 50% (320 km^3) of the total country's utilizable surface water resources (690 km^3). Contribution from snow and ice melt to the total annual river discharge has been estimated as 60%, 9% and 21% for Indus, Ganga and Brahmaputra basins, respectively (Miller et. al., 2012). For Ganga and Brahmaputra river basins, the contribution from rainfall is considered to be significant, but the rainfall being limited to 30-40 days during monsoon season, contribution from snow and glacier melt is likely to be much higher in these rivers also.

Various studies in the Himalayan region have assessed the impact of projected climate change on the hydrological regime of the snow and glacier melt fed basins, using different approaches and scenarios. Some studies have used combined cryospheric hydrological model (Immerzeel et al. 2012); some forced projected climate change scenarios on glacio-hydrological model (Immerzeel et al. 2013), others used hypothetical scenarios of increasing temperature (T+1, T+2, T+3°C) (Jain et al. 2010). These studies indicate that the drier western Himalayas exhibit different fate than wetter eastern Himalayas in context of impact of climate change.

For the western Himalayas, a hypothetical catchment was studied which is fed by glaciers and results of impact of climate change simulated using simple temperature-index-based hydro-glaciological model shows that around 2060 the flow from glacial sub-basin peaks at about 150% of initial flow while the annual mean flow will be 4% less (Rees and Collins 2006). Study by Lutz et al. (2014) presents that in all ensemble simulations, glacier melting will increase and snow melting will decrease due to rise in temperature under RCP 4.5 and RCP 8.5. It also shows that in three out of four ensembles, there will be increase of 7-12% and 2-8% in annual runoff due to accelerated melting and projected increase in precipitation in 2041-50 with respect to the reference period under RCP 4.5 and RCP 8.5, respectively. Miller et al. (2012) also confirmed that because of changing climate, glacier melt will provide increased contribution to the discharge of the basin but in future this will decrease due to reduction in melt water storage.

Some basins like Satluj in Himalayas are reported to show not much change in total streamflow but there is change in distribution of streamflow with more snowmelt runoff happening earlier (Jain et al. 2010). Another study on the same basin by Singh and Bengtsson (2003, 2005), using SNOWMOD suggests that with temperature increases of 1–3°C, snow melt would reduce by 11–23% and glacier melt will increase by 16–50%. Further, Beas basin of Western Himalayas is expected to witness decline in per capita water resources in the period of 2010-2050 (Hong et al. 2015) under climate change scenarios of RCP 2.6, 4.5 and 8.5 and also because of population growth. This is interesting to note that the climate change and development patterns together will cause a concern of water security for the downstream community in the region.

However, recent studies suggest that as most glaciers in Himalayas are losing mass at rates similar to glaciers elsewhere, dramatic changes in total runoff are not likely to occur soon, though seasonality of runoff will increase in Himalayan rivers affecting irrigation and hydropower, and altering hazards (Bolch et al. 2012). Study by Immerzeel et al. (2010) also stated that the summer and late spring discharges will reduce noticeably around the period of 2046-65.

Energy and Glaciers: Exploring the Linkages

Meltwaters from glaciers in Himalaya support mighty perennial river systems of Indus, Ganga and Brahmaputra, which have shaped the history of human civilization in the region, acting as lifeline for millions of people as well as other species thriving in the area.

Today, however, the rapid pace of globalization, urbanization and mass tourism is threatening mountain ecosystems, communities and resources. These factors leading to changes in climate and increase in level of pollution are posing a serious threat to the stability of glaciers. Glaciers act as buffers and regulate the runoff from high mountains to the plains, especially during the dry spells. Even during non-monsoon season irrigation is assured from the waters of melting snow through long, winding streams from the upper mountain reaches.

Glaciers in IGB basin

Indus, Ganga and Brahmaputra are the perennial river systems with sufficient water availability during the non-rainfall period, mainly due to the contribution of glaciers in Himalaya. However, the number of glaciers contributing to these river systems is highly uneven. According to the inventory by Geological Survey of India,

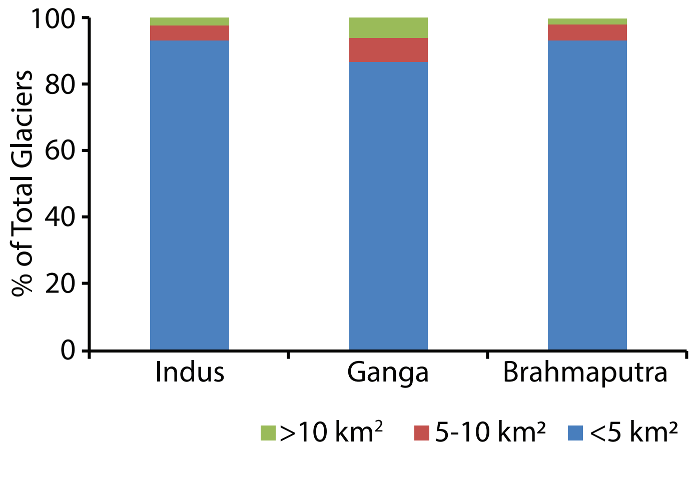

Figure 5: Glacier distribution and their size in IGB basin

number of glaciers in Indus, Ganga and Brahmaputra are approximately 7500, 1000 and 600 respectively. Besides, these river systems also receive melt water from glaciers located in China, Nepal and Bhutan. Close to 3200 glaciers in Nepal Himalaya contribute meltwater to Ganga river system.

Furthermore, glaciers in different basins vary widely in their length, area and hence, in ice volume. Close to 90% glaciers in all the river basins are smaller than 5km^2 in area and only about 260 glaciers are larger than 10 km^2. Much bigger glaciers like Siachen, Gangotri and Zemu are only a few in numbers, but mainly concentrated in Indus basin. Total ice content of the

Energy production from the IGB basin

Indus-Ganga-Brahmaputra basin is also a hub for energy production for the country. Besides hydropower production from the dams located in Himalayan states on different rivers originating from Himalaya, the basin also supports production of thermal electricity from coal as well as nuclear fuels, mining and exploration of non-renewable fuels and refining of petroleum products.

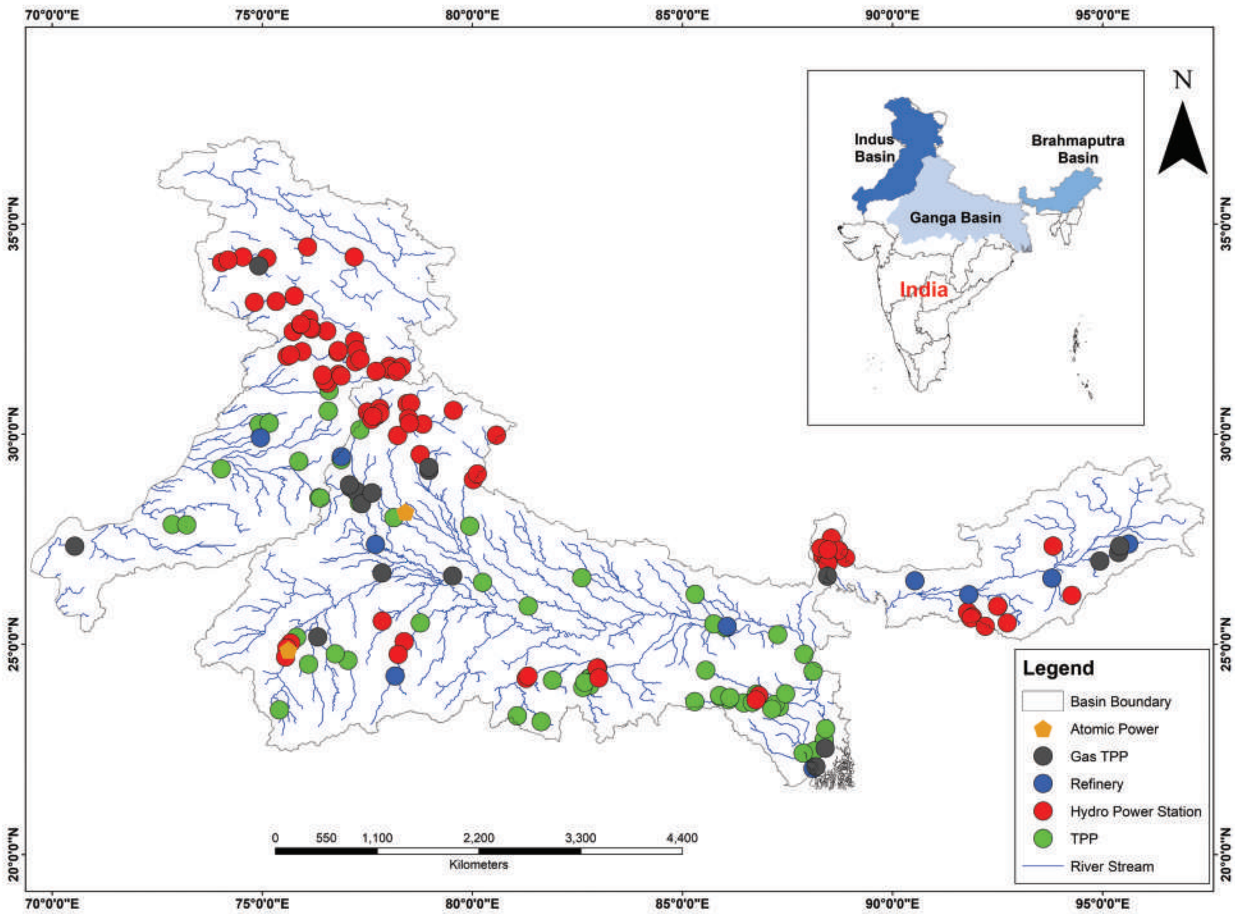

Figure 6: Energy Map of Indus-Ganga-Brahmaputra basin

Figure by Dharmesh Kumar Singh

Hydropower production from the IGB basins

81% of the total hydropower potential in the country has been assessed to be existing in the rivers flowing from Himalayan glaciers. However, considering the difficult terrain as well as other issues, only 29% of this potential has either been developed or under construction. Once developed to its full potential, additional 80000 MW electricity will be available to the country. Currently, 52% of the total hydropower electricity production in the country is being produced from the dams located in the IGB basins.

Among the three river basins, maximum potential has been assessed for Brahmaputra basin, but the level of potential development is also very low. However, 56% of the total potential in Indus basin has already been developed or is under construction, thus contributing close to 18000 MW of hydropower installed capacity. As Indus basin is fed by the maximum number of glaciers in Himalaya and the annual runoff contribution from glaciers to the basin has been reported to be close to 50%, dependence of hydropower dams in Indus basin on the Himalayan glaciers is more significant as compared to other basins.

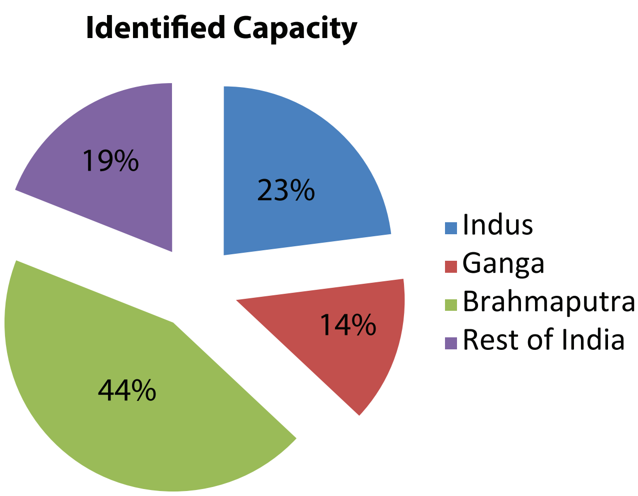

Figure 7: Identified Hydropower potential in IGB basin

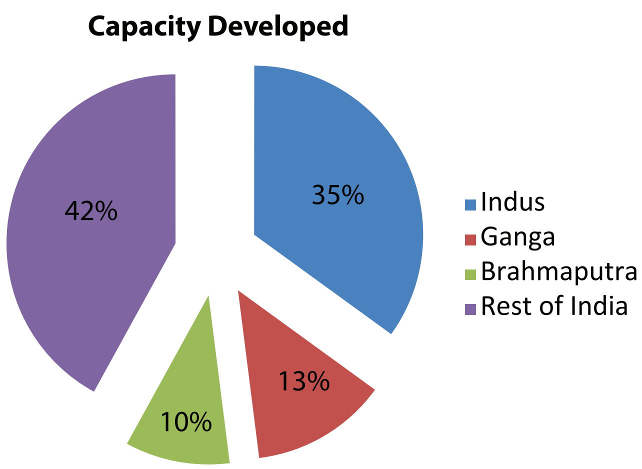

Figure 8: Developed Hydropower potential in IGB basin

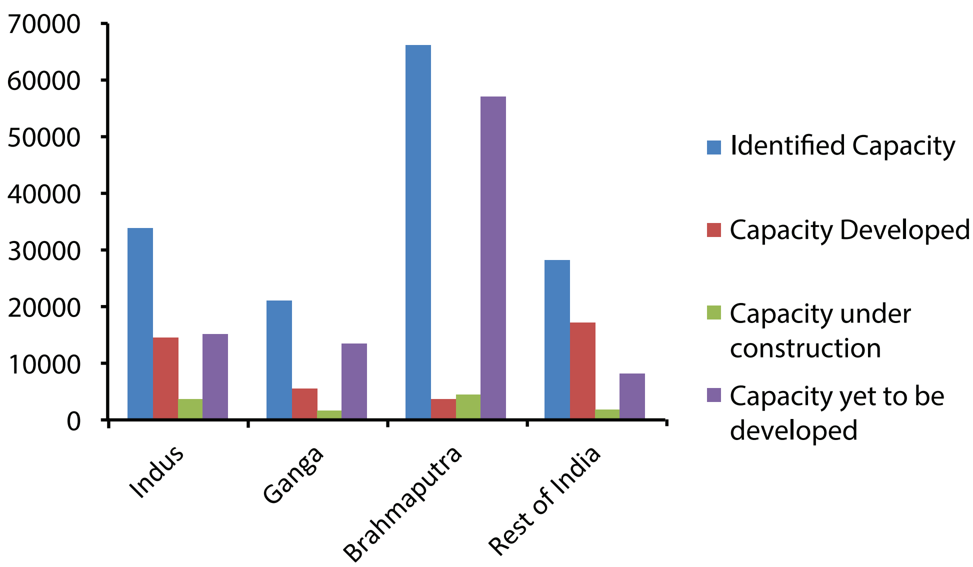

Figure 9: Installed capacity of Hydropower production in IGB basin

Among the states in IGB basin, Punjab, Uttar Pradesh, Himachal Pradesh and Jammu and Kashmir are the leading producers of hydropower in the country.

Thermal electricity production from the IGB basins

Non-renewable thermal electricity production in the country includes the production of electricity from Coal, Lignite, Gas, Diesel as well as nuclear fuels. Electricity production from all these fuels is highly dependent on availability of water and IGB basin supports all these different modes of electricity production. Almost 65000 MW of coal based electricity of the country is produced from thermal power plants located in IGB basins. This is equivalent to almost 1/3rd of total coal based electricity production in the country. Similarly, almost 24% of nuclear electricity production in the country is from the plants located in IGB basins.

Among the three basins, Ganga basin has the highest concentration of coal fired thermal power plants, followed by Indus and Brahmaputra basins. Among the states of IGB basin, Uttar Pradesh and West Bengal have the highest installed capacity of coal based thermal power plants. Punjab and Rajasthan are responsible for production of almost 90% of coal based electricity in the Indus basin.

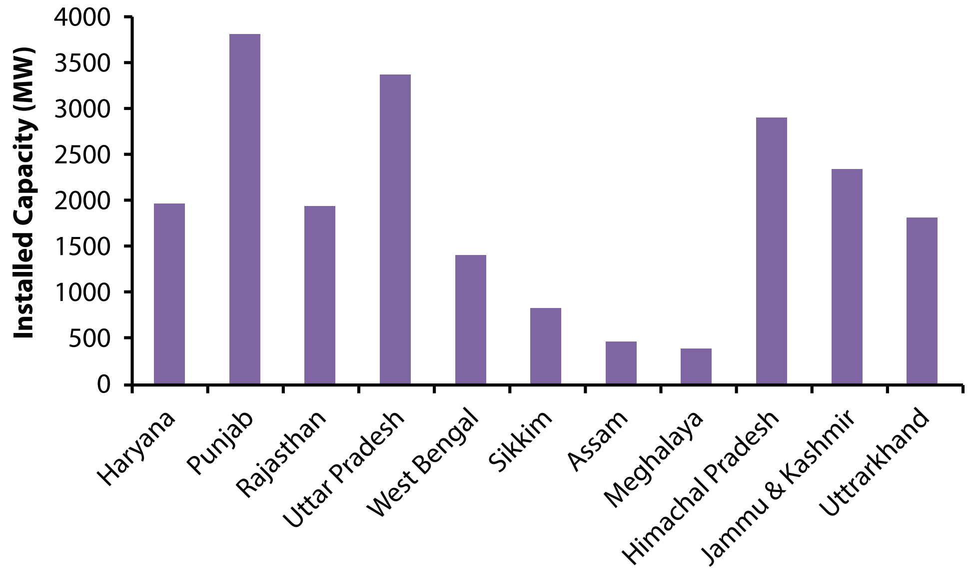

Figure 10: Installed capacity of Hydropower production in major IGB basin states

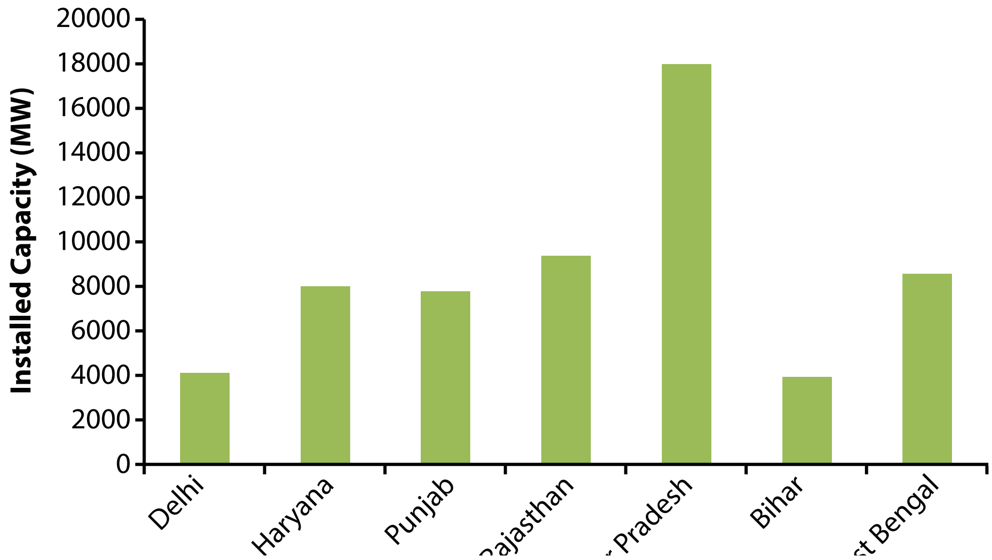

Figure 11: Installed capacity of thermal power production in major IGB basin states

Petroleum Refining Capacity of the IGB basins

IGB basin states have some of the mega petroleum refineries of the country. As such, these basins hold almost 22.5% of refining capacity in the country. Maximum refining capacity is located in Ganga basin with a total refining capacity of 36.5 million Tonnes per Annum (TPA).

Water Consumption for Energy production in IGB basin

Water for Hydropower production from the IGB basins

Hydroelectric generation is considered as a non-consumptive water user; however, some global studies have reported that hydropower is a large consumptive user of water. The amount of water lost through evaporation annually from the reservoirs is equivalent to 10% of the global blue water footprint related to crop production. While estimates for the water loss from hydropower plants in India are not available, global average estimates suggest that an average of 80 m^3/MWh water is lost as part of reservoir based hydroelectric production, which could be as low as 10-20 m^3 /MWhr in temperate countries like New Zealand. Further, the global estimates suggest that average reservoir area required per unit of installed capacity is generally 83 ha/MW.

With these estimates, it can be assessed that hydroelectric production from the IGB basins is consuming 0.25-0.5 million m^3 of water per hour, which is equivalent to 86-172 million m^3 of annual water consumption. While these are extremely conservative estimates, diurnal and seasonal variations in rate of evaporation are also likely. Furthermore, actual water required to be stored as part of the reservoir to maintain minimum reservoir level and to run hydroelectric turbines on a continuous basis, will be much higher as compared to the water consumed through evaporation.

Water for thermal electricity production in IGB Basins

Considering an average plant load factor of 80%, coal power plants in IGB basin are producing about 51,000 MW electricity per hour. We estimate that these power plants are consuming about 0.26 million m^3 water every hour, which is equivalent to 6000 million litre water every day. This is almost 4 times the minimum water requirement of total population of a city like Delhi.

Issues and Challenges

Water and energy are essential requirements for an economy's development. While they contribute independently to development, the two are inextricably connected. Energy is vital for enabling the water value chain and is needed whenever it is extracted, moved, treated, heated, pressurized, reused, or discharged. Similarly, water is needed throughout the energy supply chain, sometimes as a direct input as in the case of hydropower or geothermal energy, as a coolant in thermal power plants or more often for the extraction and processing of energy fuels. Hence, issues and challenges related to one sector have direct influence on the other.

1. Increasing Water Stress:

With increase in population, urbanization and economic development, demand for water and energy will be increasing significantly. While per capita electricity production will be increasing, per capita water availability will be decreasing in future. The situation will be at its grim peak by mid-centuary, when the per capita electricity consumption will be very high and country will reach to the level of water scarcity from the category of being water stressed.

By 2020, India will be formally categorized as a "water stressed" country, one where per capita availability of water is less than 1,000 cubic metres or less. A June 2018 Niti Ayog report grimly forecasts that water demand will be twice the present supply and India could lose up to 6 per cent of its GDP. For India although water is abundant, almost 2/3rd of the available water serves only 1/3rd of its population.

2. Increasing Energy Demand:

With increase in population, urbanization and economic development, demand for energy will be increasing significantly. Projections of energy demand in future indicate continued reliance of the country on conventional fuels to meet its energy requirement. While dominance of coal is projected to remain upto 50% for production of electricity, fossil fuels will continue to remain the key player in transport sector.

To meet the increasing demand for energy, both installation as well as expansion of power plants (both renewable as well as non-renewable) and refineries will be required, which will exert further stress on the water resources, while getting influenced with the limited availability of water, also.

3. Trade-offs between water and energy security

Interconnections between water and energy are so robust that policies and programmes related to advancement of one sector leads to generation of trade-offs and exerts negative influence on the other. For example, plans for increasing energy production have a direct bearing on the water availability of the region.

Analysis of projected future values, indicates the possible stress that energy sector could face due to depleting water resources, competing demands from other sectors, changing climate, and isolated policies. It points towards the need of conjunctive water-energy policies to ensure future power plant installation with due consideration to water availability in the region, and a mechanism of distribution of energy at all levels. This may need devising of better trade-offs to reach positive equilibrium between water and energy.

4. Impacts on Financial Viability of energy projects

Water scarcity has the potential to impact the financial viability of thermal power plants by affecting the project's rate of return. This could be due to delays in project execution leading to cost escalation and revenue losses, as well as due to affects during operating life of the project. During operations, any drop in plant load factor may reduce the revenues. It has been assessed that for each 5% drop in plant load factor results in drop of nearly 0.75% in the projects rate of return. Also, additional expenses may be required for digging ponds/ drawing canals or pipelines, for extracting water from alternate/ backup sources.

Moreover, compliance with the environmental regulations related to maintenance of discharge water quality or quantity of water extracted from the source, have cost burden on the plant operations. Quality of intake water affects the operational expenses related to production of DM water. For example, presence of colloidal silica in intake water could increase the cost of DM water production, exorbitantly.

5. Multiple regulatory institutions:

Water is under the control of multiple regulatory institutions. It is governed by both state as well as union laws and regulations. Similarly, energy sector is regulated by a different set of administrative structure spreading from national to the state level. Moreover, there is no coordination between the plans, policies, programmes and regulations related to water and energy sector. This leads to the generation of trade-offs between the policies wherein the promotion of one activity leads to negative consequences on the other.

6. Ecological Degradation

As thermal power plants require large quantity of water on a continuous basis, they are sited close to some natural or artificial water body. But huge extraction of water from the source, affects the ecological diversity of both the water body and its surroundings. Natural growth patterns of flora and fauna, relying on water body for nutrient uptake, gets affected leading to ecological degradation of the region. Moreover, discharge of water back to the source at a temperature higher than the intake water, leads to further degradation of local ecosystem.

7. Lack of clear understanding about the melt response of glaciers to climate change

Impacts of climate change on melt response of glaciers has been proved by different scientists, however, quantum of impact leading to declining ice content of Himalayan glaciers is not available. Moreover, different studies on different glaciers indicate a different melt response of glaciers due to local geographical factors. Also, actual temporal contributions of snow/ ice melt in individual Himalayan rivers has not been studied. Internationally, Himalayan glaciers have categorized as the dark spot of global climate map for which conclusive direct evidences are not available, and only indirect inferences could be drawn based on the limited research studies available for the region. This lack of clear understanding about the melt response of glaciers makes it challenging to evolve effective adaption plans for the downstream communities as well as infrastructure, and the events like Uttarakhand floods take a heavy toll on life as well as property.

8. Limited support for glacier research on Himalaya

Glacier research in the country is supported by the Ministry of Earth Sciences and the Ministry of Science and Technology through release of project grants to research institutes and universities. Primary focus of these research projects has been on understanding the cause of glacier melting and not on the effects of glacier melting on the downstream communities. This is also imperative from the fact that Ministry of Water Resources has not been having any stake on glacier research in the country.

Also, the quantum of resources required to make any significant improvement in the degree of understanding about Himalayan glacier has been limited. Ironically, annual government expenditure on research at Arctic and Antarctica is significantly higher as compared to the expenditure on Himalayan glacier research.

Recommendations

There is a high interdependence between the glaciers located in the Himalayas and the energy security of the country. Almost 33% of country's thermal electricity and 52% of hydropower in the country is dependent on the water from rivers originating in Himalaya. These rivers receiving significant part of their water due to melting of ice, glaciers make an indispensable part of India's energy security.

Reducing water footprints of energy utilities: Considering the future water demand from both upcoming thermal power plants and sectors like agriculture and domestic, reducing specific water consumption will have only a short term effect in improving overall water balance of the country. Adopting a more comprehensive approach, thermal power plants must be asked to reduce the water footprints of their operations. The concept of water neutrality must be made mandatory for power plants, which require them to return back an equivalent amount of water to the hydrological system as consumed by them. This will require them to take measures for water conservation and demand management both within and outside their boundary. Measures for promotion and implementation of micro-irrigation systems in agriculture sector, installation of water efficient fixtures in domestic sector, constructing structures for rain water harvesting, etc. will help to reduce the stress on available water resources within the watershed and augment water availability in the region.

Integrated Water Storage Policy: Reduction in free flow of rainwater leading to increase in water storage is considered as an important strategy for adaptation to climate change. For the purpose, an integrated policy needs to be formulated which may consider the water storage in its full continuum of physical water storage from groundwater, through soil moisture, small tanks and ponds to small and large reservoirs. Similar to the creation 'oil reserve capacity' in the country, a policy providing for 'water reserve capacity' should be enacted which may provision for storage of water equivalent to the country's minimal water requirement, for atleast 90 days of a year.

Developing a comprehensive understanding about the status of Himalayan glaciers: Considering the significance of Himalayan glaciers for the energy security of the country, it is necessary to develop a river basin-wise comprehensive understanding about the status of Himalayan glaciers. For the purpose, a committee of researchers shall be formed to integrate the available scientific information about the melt response of Himalayan glaciers and to develop a holistic view on status of Himalayan glaciers.

Promotion of research on Himalayan glaciers: Considering the impacts of climate change on Himalayan glaciers, and lack of confirmed scientific opinion on extent of impacts on Himalayan glaciers, it is necessary to promote the research on Himalayan glaciers. While Ministry of Earth Sciences and Department of Science and Technology have been providing support for glacier research, a concrete strategy providing direction for the future outcome of scientific research in not visible. Whereas the amount of support for research on polar glaciers is significant, an equivalent support for third pole glaciers of Himalaya is not available.

Glacier/ Source vulnerability assessment for the Hydropower plants: Environmental Impact Assessment (EIA) is a pre-requisite for the clearance of hydro-power projects from the government. But EIA conducted by the hydropower companies are mainly focussed on the likely impacts due to installation of dam on the downstream communities. However, these projects should also make a comprehensive assessment of the impacts due to climate and vulnerability to water source, on the hydropower project. This is extremely important for the projects located in Himalaya considering the impacts of climate change on its cryosphere – the water source to the project.

Watershed management by Energy Utilities: Key features of watershed management include holistic management of various aspects related to water like its supply, quality, drainage, stormwater runoff, water rights, as well as the overall planning and utilization of other resources within the watershed. Integrated watershed management has the potential to reduce water footprints of energy utilities by promoting efficient utilization of water by all the different users within the region. This could further enhance the water available for consumption to the utility. Thus, along with the efforts to reduce direct water consumption by the utility, interventions improving the water use efficiency in agricultural farms and domestic sector can lead to reduction in overall water demand within the watershed. Hence, Integrated Watershed Management should be taken up as an activity integral to the utility operation itself.

Integrated River Basin Management to rejuvenate water potential: Energy potential of a river, specifically for hydropower, is directly dependent on the overall water availability in the river and gets inversely affected with the amount of sediment being transported in the river. Furthermore, the primary hazards influencing a power project like floods and landslides in the upstream regions are directly dependent on the overall characteristics and status of the river catchment. With increasing urbanization, deforestation and climate change influences, both the water as well as energy potential of Himalayan river basins is declining. Events like flash floods in Parichu river and rivers in Uttarakhand provide conclusive evidence of increasing vulnerability of dam projects in Himalayas.

National Water Policy 2012 also recognises that Integrated Water Resources Management (IWRM) taking river basin / sub-basin as a unit should be the main principle for planning, development and management of water resources. Hence, government should focus on Integrated River Basin Management leading to rejuvenation of water potential of Himalayan rivers as well as stability of the terrain within the basin.

Assessment of GLOF potential: Lakes associated with the melting and retreat of glaciers has been considered to be possessing significant hazard potential, owing to sudden breach of natural embankments of these lakes. Occurrence of these lakes and their flood potential could have significant impact on the infrastructure downstream. Hence, it is necessary to have a comprehensive assessment of the glacier lakes occurring upstream of a hydropower project and take mitigatory measures to reduce their GLOF potential.

Joint coordination committee for Water and Energy: To facilitate an understanding of the importance of inter-linked decision making with respect to energy-water, a framework must be put in place that every decision that has an impact on energy and water linkages are taken based on rational basis and not at the cost of other. Enhancing policy coherence also implies the removal of misleading incentives that are directly leading to over-exploitation and excess usage of water and energy than necessary. The process of removal of these incentives should be gradual so as to avoid sudden shocks in pricing and supplies. Indeed political will is necessary for the removal of these incentives that are driving excessive behavior.

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APPENDIX

TERI's Glacier Research Programme

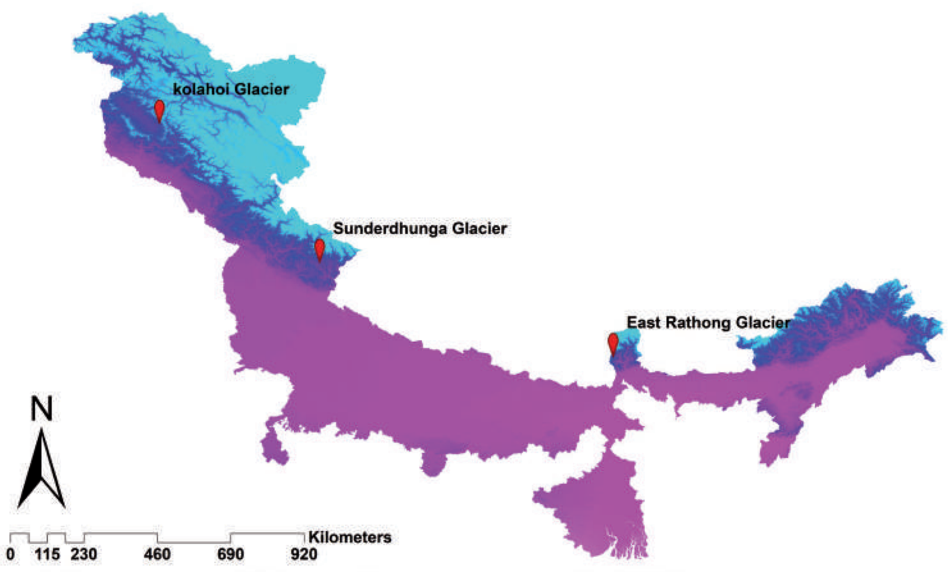
The Energy and Resources Institute, New Delhi started Glacier Research Programme in 2008 with the objective "To Quantify the linkage and dynamic relationship between meterological parameters, rate of glacier melting and meltwater discharge, in order to make an improved assessment of runoffs in the high altitude catchments of Himalayan rivers".

As part of the Glacier Research Programme, two benchmark glaciers with different climatic and geographical settings were selected. These benchmark glaciers are from Liddar valley in Kashmir and East Rathong valley in Sikkim, which are ideal for long-term measurements. The two glaciers were chosen after careful consideration keeping in view scientific relevance and logistics. The selected glaciers from different micro-climatic settings have been developed as Glacier Monitoring Observatories.

In 2015, another glacier located in the central Himalaya has been added to the network of TERI's Glacier Monitoring Observatories. The Durga Kot Glacier in central Himalaya is located in the Sunderdhunga valley in Uttarakhand.

With an integrated approach, simultaneous measurement of various parameters affecting the energy balance, glacier mass balance, as well as hydrological balance of these glaciers is being undertaken. These glaciers have been equipped with Automatic Weather Stations (AWS) with sensors for air temperature, relative humidity, wind speed and direction, net radiation, precipitation and snow depth; stream-level recorder and flow velocity metres; along with the ablation stakes and accumulation pits, for measurement of glacier mass balance.

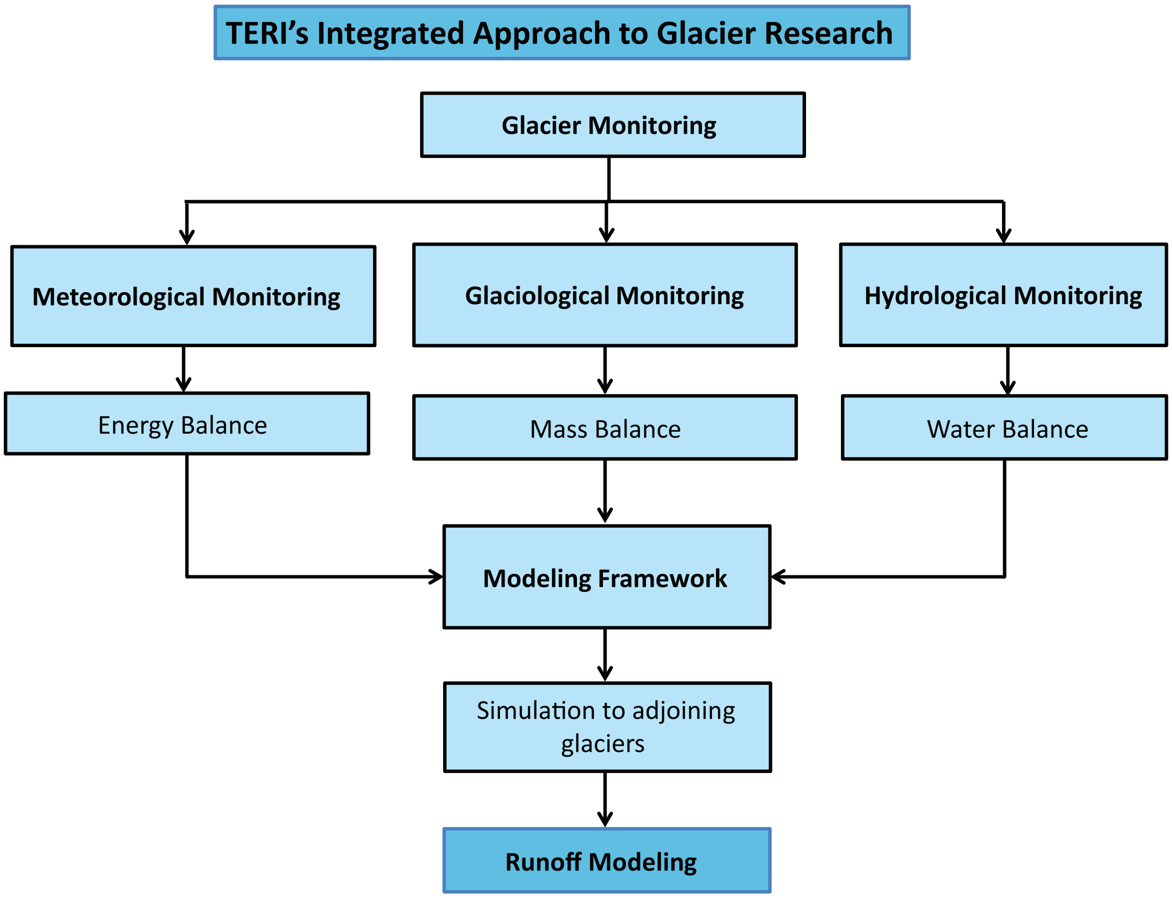
As part of the programme, TERI has executed a number of research projects on these glaciers and the glaciated streams from Himalaya. Results of TERI's glacier research has been published in various international peer reviewed journals. TERI is also engaged in capacity building as part of its Glacier Research Programme – an electvie course on



Glacier Observatory Locations in Himalaya

'Glacier Hydrology' is offered to post graduate students of TERI School of Advanced Studies and a number of PhD students are associated with the programme for their doctoral thesis. TERI has also established working relationships with a number of national and international glacier experts and has strategic understanding with various research institutes and universities.

Presently in its second phase, the analysis of satellite data and field experimentation for calculation of modelling constants is being taken up. Subsequently, the programme aims to simulate the data from these observatories to adjoining glaciers, which will feed into the development of an integrated runoff model for high-altitude catchments of Himalayan rivers.



Project Name – The response of the Hydrological System in India to Climate Change (INDICE)

Sponsor – Research Council of Norway

Duration – August 2012-August 2016

Partners:

1. Norwegian Water Resources and Energy Directorate, Norway
2. Norwegian Meterological Institute, Norway
3. Jawaharlal Nehru University, New Delhi
4. Bidhan Chandra Krishi Vishwavidyalaya, West Bengal

Aim and Objectives – To understand the impact of climate change on the cryospheric contribution to rivers in western Himalaya and the consequential impact on water resource availability and socio-economic status of the local community.

1. To assess the melt contribution of Kolahoi glacier to the downstream river
2. To develop an understanding of the nature and degree of livelihood dependence (quantitative and qualitative) of the downstream communities on melt water; and their perception about the changes in natural factors regulating the livelihoods;
3. To identify the degree of vulnerability due to variations in the melt water and changes in precipitation, on the livelihoods of the downstream population;
4. To develop an adaptation framework for the identified stakeholders to reduce the intensity of climate change impacts.

Study Area/ Location – Kolahoi Glacier and Lidar river basin, Jammu & Kashmir

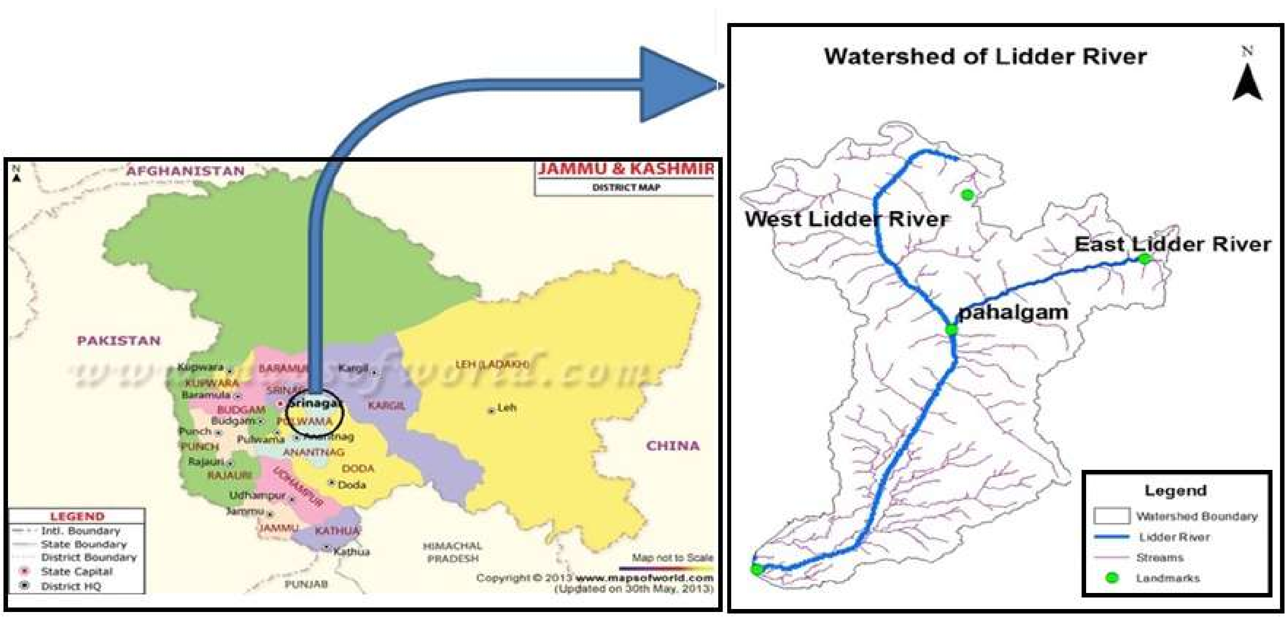
Key Activities – The project involved two specific activities: Glacier melt measurements and runoff modelling; and Socio-economic impact assessment

A. Glacier Measurements and modelling

This activity involved the glacier mass balance estimation Climate Change impacts on Glaciated area and water availability in the study region, Monitoring of Climatic Parameters, and Snow Melt Runoff Estimation

B. Socio-economic Impact Assessment

This activity involved the assessment of degree of dependence of local community of the meltwater and projection of vulnerability due to future variability in meltwater



1. Delineation of downstream impact zone and understanding the characteristics of study site
2. Stakeholder mapping and socio-economic survey to assess the degree of dependence of livelihood on melt water
3. Socio-economic Impact assessment- vulnerability to livelihood of local community for the future metl water variability in the region

Project Results –

Mass balance measurements and the analysis conducted using satellite data for the regions indicated a high rate of melting as well as glacier dynamic processes leading to deglaciation of the Lidar valley.

An extensive survey conducted in the Anantnag district of Jammu and Kashmir resulted in an improved understanding about the role of meltwater on the livelihood of local communities.

Stakeholders/ Beneficiaries – MoEFCC, Ministry of Water Resources, State Government, Disaster Management officials, Researchers, Local Community

Project Name – Climate change and its impacts hydro-meterological parametres in Pindar sub-basin, Uttarakhand

Sponsor – International Centre for Integrated Mountain Development

Duration – October 2016 - July 2018

Partner

Aim and Objectives –

1. To establish the hydro-meteorological stations in Pindar sub-basin in Uttarakhand by installing and maintaining high-altitude scientific equipment
2. To collect and analyse hydro-meteorological data from the glacier stations
3. To develop vertical profile for the study area through Digital Elevation Model, establish the flow direction, flow accumulation, stream network as well as flow velocity.
4. Understanding snow cover variation in the region
5. Establishing degree day factor for the snow catchments of the region: TERI has conducted few experiments for the purpose, and plan to elaborate it further.

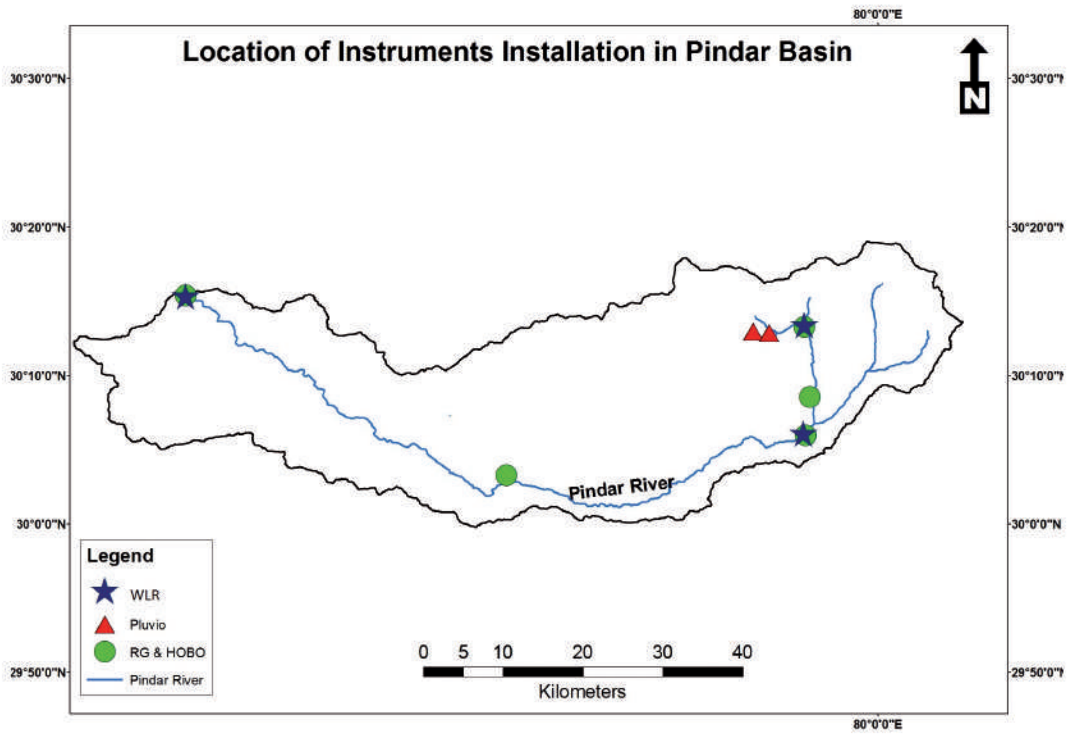
Study Area/ Location – Pindari Sub Basin

Key Activities –

1. Installation and calibration of hydro-meteorological instruments along the vertical transect of the Sunderdonga glacier valley in the Pindar sub-basin
2. in-situ measurements of the parametres influencing the runoff pattern of the stream
3. GPS profiling of the catchment
4. Analysis and modelling of the hydro-meteorological parametres influencing the runoff pattern
5. Analysis of satellite data to understand the snow cover variation and snow melt runff modelling

Project Impact –

Stakeholders/ Beneficiaries – MoEFCC, Ministry of Water Resources, State Government, Disaster Management officials, Researchers, Local Community








Project Name – Climate change and its impacts on hydro-meterological parametres in Teesta sub-basin, Sikkim (Hi-Aware, Teesta)

Sponsor – International Centre for Integrated Mountain Development

Duration – July 2016-July 2018

Partner – N/A

Aim and Objectives –

1. To strengthen the hydro-meteorological stations in East Rathong sub-basin in Sikkim by instalingl and maintaining high-altitude scientific equipment
2. To collect and analyse hydro-meteorological data from the glacier stations
3. To develop vertical profile for the study area through Digital Elevation Model, establish the flow direction, flow accumulation, stream network as well as flow velocity.
4. Understanding snow cover variation in the region
5. Establishing degree day factor for the snow catchments of the region: TERI has conducted few experiments for the purpose, and plan to elaborate it further.

Study Area/ Location – Teesta River Basin

Key Activities – Monitoring of Climatic Parameters in the sub basin area, Climate change scenario in the region, Hydrological Modelling, Vulnerability Assessment

1. Installation and calibration of hydro-meteorological instruments along the vertical transect of the East Rathong glacier valley in the Teesta basin
2. in-situ measurements of the parametres influencing the runoff pattern of the stream
3. GPS profiling of the catchment
4. Analysis and modelling of the hydro-meteorological parametres influencing the runoff pattern
5. Analysis of satellite data to understand the snow cover variation and snow melt runff modelling

Project Impact –

Stakeholders/ Beneficiaries – MoEFCC, Ministry of Water Resources, State Government, Disaster Management officials, Researchers, Local Community

Project Name – Climate Induced Mobilization of Persistent Organic Pollutants (POPs) in Rivers in India

Sponsor – The Research Council of Norway

Duration – January 2012 – December 2014

Partner – Norwegian Institute for Water Research, Norway

Aim and Objectives – The overall goal of the project was to assess the climatic controls on the environmental exposure of diffuse chemical micro-pollutants in a large hydrological system.

Study Area/ Location – Ganga river basin

Key Activities –

1. The project focussed on monitoring (on a seasonal base) exposure and fluxes of Persistent Organic Pollutants (POPs) in the Ganges River waters and its Himalayan headwaters.
2. Project also assed the possible influence of climatic and hydrologic drivers (in particular glacier melting and precipitation) expected to have an impact on releases, exposure and fate of environmental contaminants for the water ecosystem.
3. Links between climate and water borne contaminants were characterized to explore the possible implications for human exposure through water use (drinking water, irrigation, fisheries and fish farming).

Project Results –

Chemical analysis of river water samples at different locations across river Ganga established profile for POP concentration in the river water. Also, a higher concentration at the headwater locations of river Ganga indicated that glaciers could be the potential contributor of POP flux in the river.

Stakeholders/ Beneficiaries – Central Pollution Control Board, Ministry of Water Resources, state governments etc.

TERI Policy Brief / Discussion Papers

Water Resources Division

Title	Authors	Year
Critical policy interventions to fast forward micro irrigation in India	Mr Qazi Syed Wamiq Ali and Mr Nathaniel B Dkhar	2019
Drought Proofing India: Key Learnings from Bundelkhand Drought Mitigation Package	Dr J P Mishra and Dr Shresth Tayal	2018
Aligning India's water resource policies with the SDGs	Dr Girija K Bharat and Mr Nathaniel B Dkhar	2018
Sustainable Urban Development: Necessity of Integrating Water-Energy-Food Dimensions in Developmental Policies	Dr Shresth Tayal and Ms Swati Singh	2018
Water Neutral Electricity Production in India: Avoiding the Unmanageable	Dr Shresth Tayal and Ms Sonia Grover	2016
Faecal Sludge Management in Urban India: Policies, Practices and Possibilities	Dr S K Sarkar and Dr Girija Bharat	2016
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For more information, please visit: **http://www.teriin.org/**

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