Submergence Area of the Tipaimukh Hydroelectric Project, Northeast India, and its Implications on the Environment and Socio-Economy: A Case Study

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ABSTRACT

The Northeast (NE) India has immense untapped hydropower potential and is seen as the 'Future powerhouse of India'. One of the most controversial proposed hydel projects of the region is the Tipaimukh multipurpose hydroelectric project, an embankment dam of 162.8 m height with 1500 MW capacity. The project is to be built on the Barak river in the state of Manipur, NE India. The major concern with the project is the disproportionately large forestland needed to be diverted, which does not commensurate with the power generation. We hereby aim to estimate the submergence area of the project at different heights using GIS modeling tools, based on which we have estimated power density and emission of greenhouse gases (GHGs). The results indicate that the project has a submergence area of 331.31 sq. km at maximum dam height, over 73% of which is forestland. With this submergence area, the project has power density of 4.53 W/m^2, thereby eligible for carbon emission reduction credits. The annual emission of GHGs from the project at maximum height is estimated to be over 1.05 million tonne CO_2 eqv./year. The project permanently submerges 12 villages in Manipur, displacing thousands of indigenous tribal people. Another 91 villages will be affected by partial submergence. Such internal displacements would affect the socio-economy, livelihood and ethnic identities of the people, depriving them of their land rights. This may exaggerate the sensitive relationship between indigenous ethnic people. Since the region is timid with wildlife, comprising of rare, endangered and threatened species, the project would have devastating effects on the biodiversity as well. The present study reveals that if the dam height is reduced to 120 m, the submergence area as well as GHG emission reduces by 44.23%. Thus, it is recommended that the height of the project be minimized to reduce the socio-economic and environmental impacts, in addition to others.

Keywords: *Biodiversity, Climate change, Greenhouse gas, Hydropower, Power density*

INTRODUCTION

Global power demand is soaring, largely due to industrialization, urbanization and increase in use of electricity powered domestic utilities. Thus, the global energy generation increased by 2.3% in 2022, compared to 2021 (BP Statistical Review of World Energy, 2022). In accordance, the global energy-related production of greenhouse gases (GHGs) is increasing rapidly. In 1990, the global emission of GHGs from energy sector was 20.5 Gt, which soared to 39.3 Gt in 2022 (BP Statistical Review of World Energy, 2022), becoming a major global concern in this era of climate change. Thus, since long, the world is striving to reduce power production from fossil fuel, and seek renewable sources, including hydropower. In India, the year on year growth of gross energy generation in 2018-2019 and 2019-2020 was 15.45% (Energy Statistics India, 2021). India is fourth emitter of carbon, after China, US and European Union. In the UN climate conference (COP26) held in Glasgow in 2021, India has pledged to increase production of power from renewable sources, and become a net zero carbon emitter by 2070 (UNEP, 2021).

In 2001, the Central Electricity Authority of India (CEA, 2002), in its Preliminary Ranking study, identified 168 potential sites of HEPs in NE India with potential of 63328 MW. Accordingly, with less than 3% of this potential realized so far, the NE India has been recognized as the 'Future Powerhouse of India' (Menon *et al.,* 2003). However, it is pertinent to mention here that the NE India falls within two Global Biodiversity hotspots (Marchese, 2015), and has immense wildlife wealth with rare, endangered, threatened and endemic species of plants and animals (Choudhury, 2013; Chatterjee *et al.,* 2006). Further, the region is undergoing rapid orogenic and neotectonic developments (Angelier and Baruah, 2009), and falls in one of the most seismically active regions of the earth. As such, developmental projects including large HEPs are accompanied with environmental hazards and threats to the local people. Displacement of the locals and submergence of their homestead and agricultural land, and their environment threatens their livelihood, which is a major concern as raised by sociologists (Choudhury and Dey Choudhury, 2020a). This has invited conflicts between the local communities, who live a traditional way of life with intricate association with their environment, and the government. Displacement of the locals and non-judicious compensations provided to them are among the factors which often lead to conflicts (Pamei, 2001; Singh, 2003; Yumnam, 2008; Baruah, 2012; Biswas, 2012; Chowdhury and Kipgen, 2013; Sharma, 2018). The NE India is quite fragile with frequent landslides in hills, and river-bank erosion and floods in plains (NHC, 2006). Thus, dam-caused submergence of forestland in hills and dam-caused fluctuations in river water would exaggerate these processes, adding to loss of property, lives and livelihood.

Out of the hundreds of potential sites for HEPs in NE India, 20 are in the state of Manipur. One of the most controversial proposed HEPs of NE India and of Manipur is the Tipaimukh multipurpose HEP. The project is to be built on the Barak river in the state of Manipur, with submergence area in Mizoram as well. The Barak river is the lifeline of millions of people in NE India (in Manipur, Barak valley of Assam) and Bangladesh, since riparian people are largely dependent on the river for drinking water, irrigation, navigation, capture fisheries, *etc.* (Khan *et al.,* 2005; Huda, 2017; Choudhury and Dey Choudhury, 2020a). Geographically, the state of Manipur has an area of 22356 km^2, of which the central valley, called Manipur valley, comprises an area of 2040 km^2 and the rest part is Manipur Hills. Over 75% geographic area of the state is forested, mainly the hilly areas. A Land Use Land Cover (LULC) map of NE India, showing forest cover and vegetation types, is available in Choudhury and Dey Choudhury (2021). The downstream Barak valley of Assam is thickly populated having a density of 543 persons / sq. km. (Census of India, 2011), which must have largely increased by now. The project site falls in the Indo-Burma global biodiversity hotspot (Mittermeier *et al.,* 2011; Williams *et al.,* 2011; Marchese, 2015) and some splendid, rare, endangered and endemic wild species of plants and animals are found here, which are protected under Wildlife (Protection) Act, 1972. Further, the Barak-Bhuban wildlife sanctuary of Cachar district (Assam) falls in the downstream of the project (Paul *et al.,* 2023). The basic features of the project are provided in Table 1.

Another major concern has recently been raised is the eco-friendliness of HEPs. It has been identified that reservoirs of HEPs produce large quantities of greenhouse gases (GHGs), including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Bouwman *et al.,* 1995; Varis *et al.,* 2012; Barros *et al.,* 2011). The submergence area of a project is one of the major factors which determine the amount of GHGs it may produce. For most of the proposed HEPs of NE India, although studies are available on the socio-economic and geo-political complexities, there is a serious lack of studies on the actual submergence areas. This hinders the estimation of GHG production, and impacts on the forest, wildlife and the indigenous people.

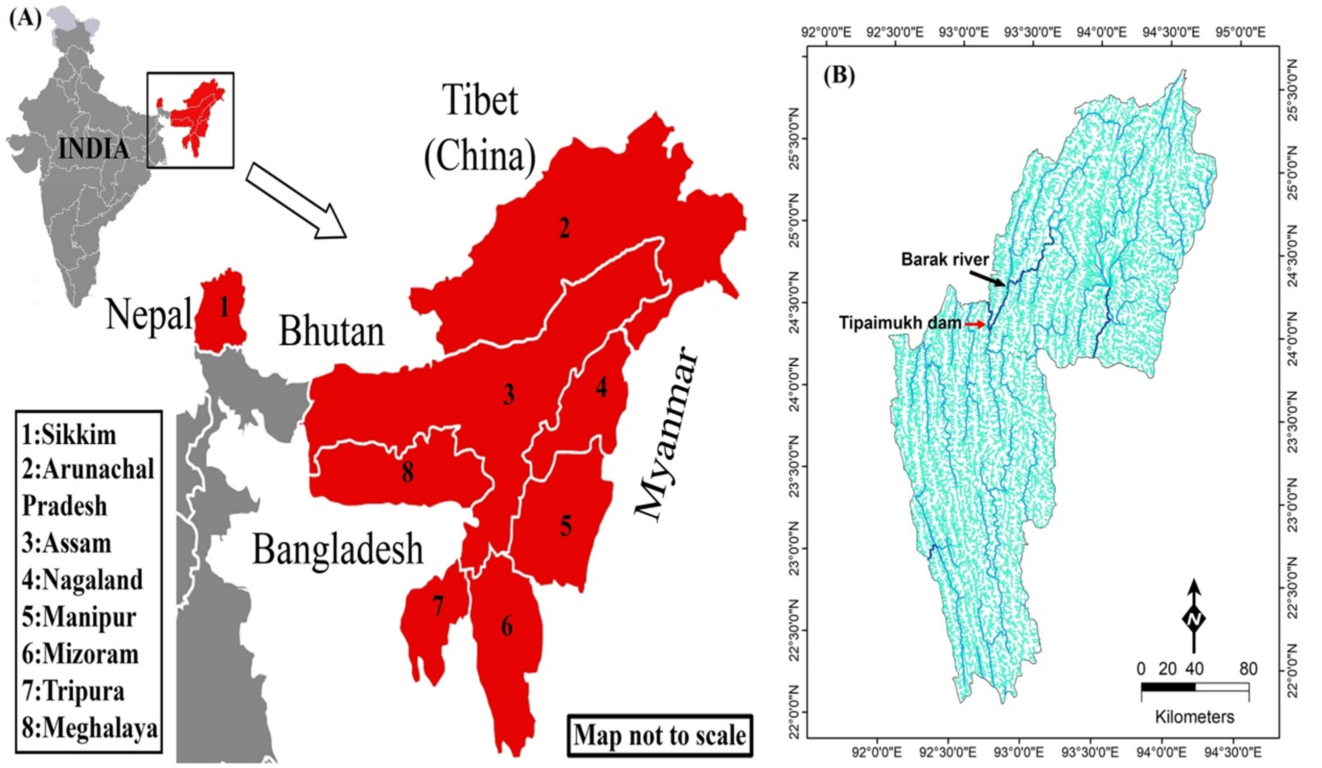

Fig. 1: (A) Map of India highlighting NE India. (B) River systems of Manipur and Mizoram showing the Barak river with its tributaries (Source: Esri, Digital Globe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community). Map of the site was prepared by using Raster images (landsat 5) downloaded from GloVis (https://glovis.usgs.gov).

As per the Census of India (2011), the human population of the state is 2721756, of which 35.1% is recognized as Scheduled Tribe, and over 50% of the population lives below poverty line (Arora and Kipgen, 2012). Agriculture and livestock contributes 20.54% of the gross state domestic product of Manipur in 2011-2012. The annual area under *Jhum* cultivation (a slash-and-burn type of shifting cultivation) in Manipur is 90,000 Ha, with 70000 *Jhumia* families (Census of India, 2011; NEC, 2015). Manipur Hills is rich in natural resources, including rivers, fertile soil, forest cover and minerals. The tribes living in the hills collect firewood, timber, bamboo, cane, resin, gums, oils, fibers, thatch, honey, medicinal plants, *etc.* which serves their household needs, and is a source of local economy. These people perform agriculture in the hills, which is supplemented with weaving, fishing, carpentry, embroidery, and other crafts. Agricultural activities, including *jhum* cultivation, and extensive deforestation, has made the ecology of the hilly tracts of Manipur fragile (Raatan, 2004; Singh, 2007-08).

As per the project proposal, the submergence area of the Tipaimukh HEP is 311 sq. km., while Singh (2017) estimated the submergence area to be 383.527762 sq. km., thereby questioning the actual submergence area. Furthermore, Singh (2017) used ASTER DEM for their study, which is less efficient in accuracy in mountainous areas (Khasanov, 2020). Thus, we hereby attempt to map the submergence area of the project using GIS modeling tools using the more accurate Space Shuttle Radar Topography Mission (SRTM) 1-Arc Digital Elevation Model (DEM) data sheet at different dam heights. Based on the findings, we estimated power density – which is a parameter to determine carbon reduction credits of any HEP (Kibler *et al.* 2012), and production of GHGs, *viz*. CO_2, CH_4 and N_2O. While the study would enable scientists to perform a cost-benefit analysis with respect to socio-economical and bio-physical aspects, it may serve as a baseline for the Govt. in their decision-making.

METHODOLOGY

The Study area

The Tipaimukh project is a proposed HEP to be constructed in the Barak river, in the Tipaimukh village of the Pherzawl district of Manipur, which shares border with the Indian state of Mizoram (Fig. 1). The Barak river originates in the Manipur hills, has a serpentine hilly course, and confluences with its tributary Tuivai. The Tuivai river originates from *Mizo* hills in the state of Mizoram (Choudhury *et al.,* 2019). The HEP is proposed to be built 500 m downstream of the confluence, and its reservoir extends to both Manipur and Mizoram. The Barak river then enters the plains of Assam, forming a valley known as Barak valley. Following a course of approximately 100 km in Assam, the river then crosses the Indo-Bangla border. This river is one of the main contributors of water to the Megna river that forms the Ganges-Brahmaputra-Megna (GBM) river basin (Choudhury *et al.,* 2019).

The controversy related to the Tipaimukh project is both local as well as trans-boundary. The environmentalists are concerned about the disproportionately higher submergence area of the project compared to its power generation potential (Choudhury and Dey Choudhury, 2021). There are concerns in Barak valley (Assam) regarding the likely impacts and hazards this project may cause, threatening the lives and livelihoods of a large population (Choudhury and Dey Choudhury, 2020a, 2021). Bangladesh has been protesting against the project, making it another trans-boundary river-linked source of conflict between the two riparian nations (Huda, 2013, 2017; Huda and McDonald, 2016; Huda and Ali, 2018). Since the entire NE India falls in the highest seismic zone (zone V), any dam burst due to earthquake or reservoir-induced seismicity is surmised to have a devastating impact.

Table 1. Basic information on the Tipaimukh project, Manipur, NE India

GPS Location	$24^0$14' N Latitude and $93^0$13' E Longitude
River basin	Barak river basin
Location of the reservoir	Manipur and Mizoram
Local of the dam	Tipaimukh village, Pherzawl district, Manipur
Downstream area	Manipur and *Mizo* Hills, Barak valley of Assam
Installed capacity	1500 MW
No. of turbines	6
Proposed Dam Height	162.8 m
Proposed Dam length	390 m
Project type	Large, Multi-purpose
Implementing agency	Joint Venture among Govt. of Manipur, NHPC and SJVN
Estimated cost	Rs. 8,138.79 crore (as of 2008)

The modeling analysis

Space Shuttle Radar Topography Mission (SRTM) 1-Arc Digital Elevation Model (DEM) data sheet of 30 m resolution was use to delineate our hydrology model. A total of 11 sheets were downloaded from USGS (https://glovis.usgs.gov) to show complete river and drainage model of two Indian states namely Manipur and Mizoram. For that, we used hydrology tool of ArcGIS 10.5, to show stream networks. This river network model was then intersected with the elevation model, in order to obtain watershed areas. Upon obtaining the idea of watershed areas, the raster was reclassified. After reclassify, this raster was converted into polygon. With help of editing tool, areas which were outside the appropriate reservoir of the dam were omitted. Then, the elevation raster was masked with the polygon. For calculation of the areas, this new raster was reclassified accordingly with the previous model. After assigning the appropriate classes, we calculated its area based on the total cell count in each class multiplied by its cell size (30 m^2) dividing this value with 10000, to obtain the result in hectares, which were then subsequently converted to square kilometre (sq. km.). Since the height of the dam would be 162.8 m, and the elevation of the riverbed is 49 m above mean sea level (msl), and considering the depth of the water to be 4 m, we estimated the submergence area at 53 m (base level), 93 m, 132 m, 172 m and 212 m elevation above msl, corresponding to dam heights of 40 m, 80 m, 120 m and 163 m.

Estimation of Power density

Power density was calculated in Watt per square meter of surface area of the reservoir of the project (W/m^2). As per United Nation's Framework Convention on Climate Change (UNFCC), a project with power density of less than 4 W/m^2 is not eligible for CO_2 emission reduction credits, owing to the emissions from the reservoir itself. A project with power density of 4.1 – 10 W/m^2 is eligible with emission reduction factor of 90 g CO_2 equivalents/ kWh, and those with power density >10 W/m^2 are eligible with negligible project emissions (Brown *et al.,* 2009; Kibler *et al.,* 2012). The power density was also calculated from the reservoir surface area reported by Singh (2017), and compared with the present findings.

Estimation of GHG Emission

The production of GHGs from HEPs is a function of the surface areas of reservoirs of the projects (Choudhury and Dey Choudhury, 2020a, 2021). These gases are produced due to the microbial decomposition of organic matter trapped in the reservoirs, and are released from the reservoirs through various means including diffusion, bubbling, degassing from spillways, turbines, and from downstream river course (Bastviken *et al.,* 2004, 2008, 2011; Deemer *et al.,* 2016). The annual emission of GHGs, viz. CO_2, CH_4 and N_2O, were estimated for the project, and the annual carbon equivalents were calculated for different heights of the project. Emissions of CO_2 and CH_4 were estimated at the rates of 4000 mg/m^2/day and 137 mg/m^2/day respectively, which are the average rates of emission of GHGs by the reservoirs of HEPs (Varis *et al.,* 2012). As per Varis *et al.* (2012), the emission of CO_2 from tropical reservoirs HEPs may be as high as 10400 mg CO_2/m^2/day, and the average rate of emission is 4000 mg CO_2/m^2/day. For CH_4, the emission can be as high as 1140 mg CH_4/m^2/day, and the average rate is 137 mg CH_4/m^2/day. The annual average emission of N_2O from reservoirs of HEPs was estimated at the rate of 97 µM/m^2/day (*Guérin et al.* 2008). We have used these average rates for estimating the emission of the GHGs for the Tipaimukh project, and calculated the same for one year for each GHG. The emissions of the GHGs were calculated for the estimated reservoir surface areas (submergence areas) at different heights of the dam. The annual CO_2 equivalents were calculated (in units of Kg CO_2, CH_4 and N_2O/year) by the 100-year global warming potential (GWP) of each gas compared to CO_2. It is reported that the 100-year GWP of CH_4 is 25 times of that of CO_2, and that of N_2O is 298 times of CO_2 (Varis *et al.* 2012; Deemer *et al.* 2016). These conversions were performed to calculate the annual total GHG emission. The emission was also calculated from the reservoir surface area reported by Singh (2017), and compared with the present findings.

RESULTS

Submergence area

The height of the project as per the DPR is 162.8 m, and for the ease of calculation we have estimated the submergence area at a maximum height of 163 m, similar to Singh (2017). The estimations are based on digital elevation maps. Since the project site has an elevation of 49 m above mean sea level (amsl), considering water depth of 4 m, the baseline water level is at 53 m amsl. Submergence areas at different dam heights (40 m, 80 m, 120 m and 163 m) were estimated so that recommendations for changes in the proposed structure may be made in order to minimize the environmental impacts and emission of GHGs. The GIS modeling analysis revealed that the water surface area at baseline water level is 2.57 sq. km. However, with dam height of 40m, 80m, 120m and 163m above the baseline water level, the submergence area would be 27.59 sq. km., 89.64 sq. km., 184.78 sq. km. and 331.31 sq. km. respectively (Fig. 2; Table 2). Thus, the submergence area would increase by 10.73-fold, 34.86-fold, 71.86-fold and 128.85-fold at dam height of 40m, 80m, 120m and 163m respectively.

The submergence area estimated in the present study is 1.065-fold higher than the area reported in the DPR of the project. However, the submergence area reported hereby is 13.62% less than the submergence area estimated by Singh (2017). The difference might be because of the use of SRTM DEM in this study, while Singh (2017) used ASTER DEM. It has been reported that SRTM DEM outperforms ASTER DEM in evaluation of surface area of water reservoirs in mountainous areas in its accuracy of vertical elevation (Khasanov, 2020). Thus, we believe that the submergence areas reported in the present study are more accurate, and is at par with the DPR of the project. The result is specifically important since submergence area has implications in socio-economic impacts, power density, GHG emissions, and thereby affects carbon emission reduction credits for any hydel project (Kibler *et al.* 2012).

Power density

With a submergence area of 331.31 sq. km., and installation capacity of 1500 MW, the power density of the project is calculated to be 4.53 W/m^2. With this power density, the project is eligible for carbon emission reduction credits at 90 g CO_2 eqv./ kWh. However, if calculated based on the submergence area as reported by Singh (2017), the power density would be 3.91 W/m^2 and thus making the project ineligible for the credits. The project thus requires 220873.3 m^2 submergence area per MW of power produced, which is thus staggeringly disproportionate. The analysis shows that with a 26.38% reduction in dam height to 120 m, the submergence area would reduce by 44.23%. Again, if compared with similar projects of NE India, e.g. Lower Subansiri HEP, Arunachal Pradesh, dams with similar heights may have over 1500 MW power generation capacity. Thus, the project height may be reduced to minimize submergence area without affecting power density.

Emission of GHGs

Emission of CO_2, CH_4 and N_2O were found to be 4.84 lakh tonne/year, 16567 tonne/year and 516.27 tonne/year, and the total emission of GHGs was found to be 1.05 million tonne CO_2 equivalents/year at maximum dam height, i.e. 163 m. The emission of GHGs at different dam heights has been mentioned in Table 2. It is evident that at 120 m dam height, the emission of GHGs reduces by 44.23%. With the estimated submergence area reported by Singh (2017), the total emission was found to be 1.22 million tonne CO_2 eqv./year. Since Singh (2017) has reported the submergence area to be quite more than the present findings, the estimated amount of GHG has been found to be higher.

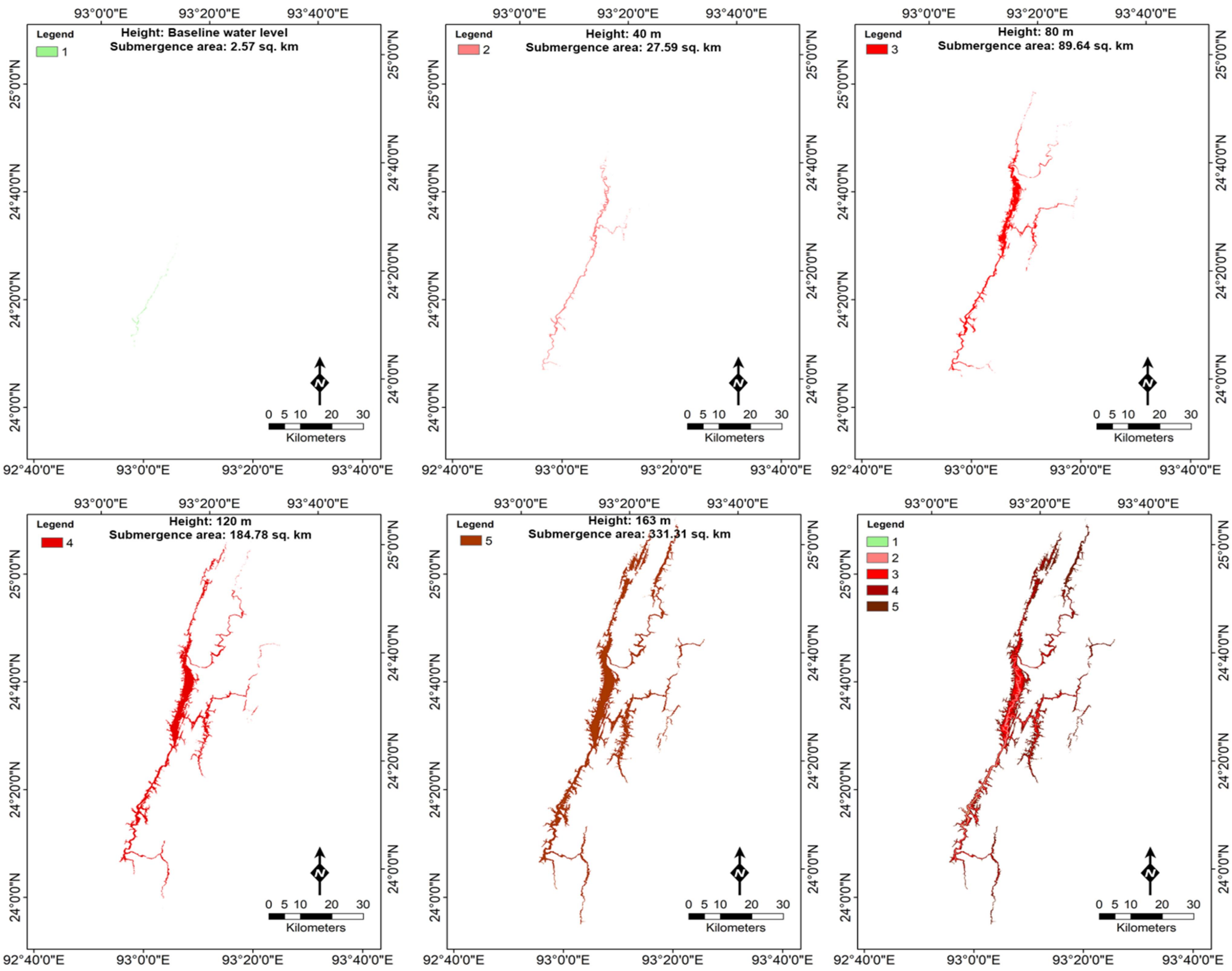

Fig. 2. Map showing submergence areas of the Tipaimukh project at different dam heights, viz. baseline water level, 40 m, 80 m, 120 m and 163 m, determined using GIS modeling.

Table 2. Submergence area and emission of different GHGs from the Tipaimukh project at different heights as estimated in the present study.

Dam height (in m)	Submergence area (in sq. km.)	GHG emission (in kg/year)			CO_2 eqv. (in kg/year)
		CO_2	CH_4	N_2O	
No dam	2.571	3754090.07	128577.58	4006.78	8162549.94
40	27.594	40287154.88	1379835.06	42998.90	87596703.30
80	89.638	130871495.49	4482348.72	139680.51	284555005.06
120	184.781	269779398.00	9239944.38	287938.36	586583638.22
163	331.311	483712600.00	16567156.55	516271.49	1051740417.77

DISCUSSION

The primary aim of the present study was to estimate the submergence area of the proposed Tipaimukh HEP of Manipur, NE India. The submergence area of a project has implications on the socio-economy, geo-politics and bio-physical aspects (Brown *et al.,* 2009). Furthermore, estimation of GHGs and power density, and thereby carbon emission reduction credits are reported hereby which will incentivize decision and policy making by implementing agencies. The present GIS modeling study revealed that the reservoir surface area of the Tipaimukh project is 331.31 sq. km. The map (Fig. 2) reveals that the submergence area or the reservoir of the Tipaimukh project extends well into the Barak and Tuivai rivers including their smaller streams, rivers and rapids, and a large tract of forestland. As per Singh (2017), the submergence area at 163 m is 383.527762 sq. km. The difference with our findings may be due to use of SRTM DEM images in our case, instead of ASTER DEM images by Singh (2017).

The forestland required to be diverted for the construction of the Tipaimukh HEP is more than 100-times the average rate of diversion of forest land in India since the enactment of the Forest (Conservation) Act, 1980 (Osmani, 2017) – the only piece of legal instrument that prevents state governments from diverting forest land for non-forestry purposes (Kant, 2003) (Osmani, 2017). This raised concerns over the project and its location. Interestingly, as per the report of Forest Advisory Committee (FAC), the diversion of forest land for the project is 227.775 sq. km. in Manipur and 15.516 sq. km. in Mizoram (MoEFCC, 2012, 2013a, 2013b, 2013c). In Manipur, the submergence area includes 219.5264 sq. km., 7.5946 sq. km. and 0.754 sq. km. for reservoir, project area and diversion of national highways respectively. In Mizoram, the submergence area includes 14.89 sq. km., 0.5 sq. km. and 0.126 sq. km. for reservoir, project area and diversion of national highways respectively (Osmani, 2017). Unfortunately, a staggering 73.433% (243.291 sq. km.) of the total submergence area (331.31 sq. km.) of the project is forest land.

Fig. 3. Photograph of the Tuivai river (just upstream of its confluence with the Barak river), and the forestland which would be submerged by the Tipaimukh project. Photograph obtained from Dr. Anwaruddin Choudhury, a very renowned naturalist from NE India.

The project site and the submergence area of the Tipaimukh HEP is dominated by the *Hmar* and *Naga (Zeliangrong)* people (Dikshit and Dikshit, 2014). There are several ethnic communities in the state of Manipur and Mizoram, and inter-ethnic relations have often been sensitive. Of late, there have been serious ethnic clashes between hill and plain dwellers of Manipur over land rights, causing loss of lives, and internal displacements of thousands of people (Kaushik and Rajesh, 2023). These communities are largely dependent on their environment for livelihood. Due to poor transportation facilities, connectivity and other infrastructures, these tribes are socio-economically backward (Raatan, 2004; Singh, 2007–2008). The hydel project would submerge 12 villages inhabited by these communities, comprising a population of over 2000, as on 2011, which must have experienced a large increase by now. The confluence of Tuivai and Barak rivers is a sacred place for *Hmar* people. Thus, the local people who would be displaced by the Tipaimukh HEP by submergence of their homeland, agricultural land and sacred place are worried about their livelihood sources, culture, religion, identity and demography (Arora and Kipgen, 2012). The socio-economic, bio-physical and geo-political impacts of the Tipaimukh project have been reviewed in detail by Choudhury and Dey Choudhury (2021).

The submergence areas is particularly noteworthy since the project site and its reservoir fall in the Indo-Burma Biodiversity hotspot area (Mittermeier *et al.* 2011; Williams *et al.* 2011; Marchese, 2015), and includes parts of Tuivai Riverine Reserve Forest (RRF), Tuiruang RRF and Inner Line Reserve Forest (ILRF). The vegetation type of the area is subtropical evergreen and semi-evergreen forest (Fig. 3). Some splendid, rare, endangered and endemic species of plants and animals are found here. Some of the IUCN redlisted 'Endangered' fauna include Bengal slow loris, Hoolock gibbon, Hog deer, Dhole, Fishing cat, Tiger, Phayre's langur, *etc*. Some of the 'Vulnerable' animal species include Asiatic black bear, Pig-tailed macaque, Assamese macaque, Stump-tailed macaque, Gaur, Marbled cat, Clouded leopard, Smooth-coated otter, Oriental small-clawed otter, Sambar, Capped langur, Chinese goral, Binturong, *etc*., and some 'Near threatened' species are Malayan sun bear, Hog badger, Large Indian civet, Asian golden cat, leopard, *etc*. Others include Barking deer, Chinese pangolin, Crestless Himalayan porcupine*, etc*. (Choudhury, 2013). All these species are protected in India under Wildlife (Protection) Act, 1972. Mithun (Gayal), a semi-domestic cattle species found in Manipur is a crucial livelihood source for the hill tribes (Choudhury, 2013). These species are found in the submergence areas and project sites of the proposed Tipaimukh HEP (Choudhury, 2013; Choudhury and Dey Choudhury, 2021). Many of these species have also been reported by the FAC (MoEFCC, 2013a,b). The place is a splendid habitat of the 'Critically Endangered' crocodilian species, the Gharial (Singha *et al.* 2020). Further, deforestation, *jhum* cultivation, soil erosion, landslides, *etc*. are the existing environmental issues here in the Manipur Hills, including the project site (Dikshit and Dikshit, 2014). It has been observed by the FAC that large scale *Jhum* cultivation and deforestation have occurred in the submergence area, and thus the dam would thereby exacerbate soil erosion and landslides (MoEFCC, 2013a,b). With submergence area of 331.31 sq. km. at maximum reservoir level, the project has been found to be eligible for carbon emission reduction credits with power density of 4.53 W/m^2. However, with the submergence area as estimated by Singh (2017), the project is ineligible for carbon emission reduction credits, since the power density would be 3.91 W/m^2. It may be mentioned here that Singh (2017) used ASTER DEM for their study, while we have used SRTM DEM. SRTM DEM gives much better absolute vertical accuracy in the region (Elkhrachy, 2018; Khasanov, 2020), especially for estimating submergence areas of reservoirs in hilly terrains. Furthermore, our result on submergence area is at par with the DPR of the Tipaimukh project. Nevertheless, since carbon emission reduction credit is measured from installed capacity and reservoir surface area, it is pertinent to mention here that both these parameters are variable. While rainfall, reservoir storage and dam operations would affect submergence area, the amount of water stored, siltation of the dam and operation procedures would affect the actual power generated. Since the calculations are based on modeling analysis of reservoir surface area and considering the maximum installed capacity, the findings may be highly variable (Choudhury and Dey Choudhury, 2020b). The proposed project site falls in the highest seismic zone (zone V) and has already experienced earthquakes of magnitude over 8 in Richter scale in last 50 years. In addition, the reservoir-induced seismicity is another serious concern of this project. Thus the project would be a serious hazard for the people living in the downstream river basin with potential to cause devastating floods due to dam bursts. It is estimated that over 40 million people of Bangladesh would be threatened with water scarcity and desertification (Asaduzzaman and Rahman, 2015).

The emissions of CO_2, CH_4 and N_2O from the project were found to be 4.84 lakh tonne/year, 16567.16 tonne/year and 516.27 tonne/year respectively, and the total emission to be 1.05 million tonne CO_2 eqv./year. However, as expected, with the estimates of surface area available from Singh (2017), the total emission was found to be 1.22 million tonne CO_2 eqv./year. The present study is particularly important since the dams of the tropical and sub-tropical regions are known to produce more GHGs compared to dams of other geographic regions (Barros *et al.,* 2011; Varis *et al.,* 2012). The approximate life cycle emission of GHG has been estimated to be 162-250 Kg CO_2 eqv. / KWh for newly flooded boreal reservoirs, while for reservoirs of tropical HEPs the same has been reported to be 1300 – 3000 Kg CO_2 eqv./KWh (Steinhurst *et al.,* 2012). Importantly, for run-of-river (RoR) hydel projects, the rates of emissions have been reported by the study to be 0.5 – 152 Kg CO_2 eqv. / KWh. This suggests that RoR model of HEPs would be a better choice in tropical areas. Ironically, the rates of emission from coal-fired power plants is estimated at 900-1200 Kg CO_2 eqv. / KWh. Barros *et al*. (2011) estimated the global production of GHG from HEPs for a total of 3.4×10^5 sq. km. of reservoir surface to be 288×10^{12} g CO_2 eqv./year. On the other hand, the average rate of emission of CO_2 and CH_4 from tropical HEPs were found to be 4000 mg CO_2/m^2/day and 137 mg CH_4/m^2/day respectively (Varis *et al.,* 2012), which are at par and even higher than those produced by thermal power plants, thereby questioning the carbon emission reduction credibility and eco-friendliness of HEPs. Being located in tropical region, the Tipaimukh project is also surmised to produce similar amounts of GHGs. The emission of GHGs from HEPs of NE India has been detailed in Choudhury and Dey Choudhury (2020b). This study reports the highest emission of GHGs from Pare HEP, Arunachal Pradesh at 3.54 million tonne CO_2 eqv./year, which is 3.37-folds higher than the Tipaimukh project. On the other hand, the least emission was reported from the Thoubal HEP of Manipur, with emission of 3.71 lakh kg CO_2 eqv./year.

In addition to the environmental impacts of submergence area of the project, the Tipaimukh project also has immense socio-economic impacts. The confluence of the Barak river with Tuivai river is known to the indigenous *Hmar* tribe as '*Ronglevaisuo'*. The site is historically and spiritually important for them, as well as several other tribes of NE India (Singh, 2003). The submergence area of the project includes heritage sites, including the famous Barak waterfalls, and *Zeilet* lake of Kabui (Singh, 2003; Arora and Kipgen, 2012). It is estimated that a hydel project with 1000 Ha (say) of submergence area requires, on an average, another 1500 Ha – 2500 Ha of forestland for roadways, future expansions, colonies, townships, *etc*. (Kant, 2003). Further, it is being worried that settlement of outsiders in the area will lead to loss of cultural heritage, sources of livelihood, and religious and ethnic identities of the local tribes (Singh, 2003). Since 12 inhabited villages of Manipur would be fully submerged, and another 77 villages of Manipur and 14 of Mizoram would be affected, the local people would lose homestead and cultivable land, thereby affecting their livelihood (Pamei, 2001; Singh, 2003; Yumnam, 2008; Arora and Kipgen, 2012). This would cause internal displacement of these tribal communities, incite competition and conflicts for land and forest resources, sprain social cohesion, and cause landlessness and poverty, and higher anthropogenic pressure on the remnant forest (Webber and McDonald, 2004). Barring the fully submerged villages, the people of the other villages have not been considered project-affected, and are not entitled to any compensation as per the environmental management plan (EMP) (MoEF, 2007). As per the report of the FAC, the project would displace 557 families of Scheduled Tribes having a population of 2027 (MoEFCC, 2007), which must have increased largely since then. On the other hand, different non-Govt. organizations and researchers have reported the affected people in Manipur to be as high as 40,000 (Das, 2007). Since May 2023, there have been violent ethnic clashes between hill and plain dwellers over land rights, which has already taken a death toll of at least 125 people, and displaced over 40,000, and this continues as on the date of writing this manuscript (Kaushik and Rajesh, 2023). The displacement of the tribal people due to such HEPs would add to the ethnic conflicts in the state.

RECOMMENDATIONS

Based on the findings of the present study, the following recommendations are hereby provided for the present Tipaimukh HEP, which may well translate for the other proposed HEPs of NE India.

- **Reducing submergence area:** Since the submergence area of the Tipaimukh HEP has been found to be disproportionately high, it is suggested that the same be minimized in order to reduce impacts on the environment and socio-economy of the local people. This may be done by, first reducing the height of the dam, as depicted in Table 2. As found in the present study, a reduction of height of the dam by 26.38% to 120 m would reduce the submergence areas and consequently the emission of GHGs by 44.23%. It may be mentioned here that Lower Subansiri HEP of Arunachal Pradesh, NE India, with height of 116 m has an installed capacity of 2000 MW, suggesting that if re-designed to a lower height installed capacity can still be maintained. Second, the implementing agency and the Govt. should seek out alternative sites for the project, with due GIS modeling studies such that the submergence area may be lesser and power density is higher. The FAC in its meeting dated 11th - 12th July, 2013 have suggested that the implementing agency should look for feasibility of smaller dams requiring diversion of smaller areas of forest land and should be commensurate with the power generation (MoEFCC, 2013a,b,c). The FAC in its meeting in 2012 has also recommended for reduction of dam height to minimize the impacts (MoEFCC, 2012).

- **Reducing reservoir storage:** Since the amount of GHGs produced depends on reservoir storage and surface area, it is recommended that the storage capacity should be reduced. In this regard, the proposed project should be a run-of-river dam with minimal storage. This would maintain ecological flow of the river, and thus cause lesser impacts on the hydrology in the downstream. Moreover, with lesser storage, the rate of aerobic decomposition would be higher, which would favour production of CO_2, rather than the more noxious CH_4.
- **Research and EIA:** It has been observed that the EIA report of most of the proposed / under-construction HEPs of NE India are seriously erroneous. It is hereby suggested that proper EIA should be conducted for the Tipaimukh, as well as other HEPs of NE India, giving due importance to all the wildlife species which may be directly or indirectly affected by such HEPs. Since NE India is timid with a rich wildlife wealth, including species of socio-economic and medicinal uses, EIA should be sincerely done, and should not be treated as an instrument for getting the projects cleared. Further, geological studies, including GIS modeling of erosion and landslide prone areas, and forest cover should be carried out to identify potential risks of HEPs. Selection of project sites should not be based solely on feasibility of power generation. Hydrological impacts, including water quality, sediment load, siltation, *etc*. should be studied beforehand, and mitigation measures should be taken accordingly. While the EIA report of the Tipaimukh project (prepared by Agricultural Finance Corporation of Mumbai, India) mentions the biodiversity of the submergence and catchment areas, it scrupulously mentions that there is no important flora or fauna! The report does not mention about the richness, evenness, abundance and density of plant species, phytoplanktons or zooplanktons. It may be mentioned here that since the area falls in the Indo-Burma biodiversity hotspot, it is

very rich in biodiversity with many species which are globally threatened, and redlisted by IUCN as 'endangered', 'vulnerable', *etc*. For the Tipaimukh project, the Govt. of Mizoram submitted a proposal for diversion of 1551.60 Ha of forestland for the project in 2011. The letter mentions that there is no rare / endangered / unique species in the forestland, and that the area is not vulnerable to erosion. Similarly, the Govt. of Manipur submitted a proposal for diversion of 2582214 Ha of forest land. This proposal mentions that there is no rare / endangered species in this forestland. The FAC has pointed out that the project would affect 78,16,931 trees, and 27000 bamboo culms. The Principal Chief Conservation of Forest, Manipur, noted that the adverse impacts of the project and the diversion of the forest land on flora, fauna, biodiversity, micro-climate, *etc*. cannot be mitigated unless compensatory afforestation are done in upstream areas (MoEFCC, 2012). The public hearings have been regarded 'farce' by the local people, which is another major concern (Akoijam, 2006). The EIA report of the project failed to address the four Mahseer fish species, for whom the Barak river is an important habitat and safe abodes. Among these, *Tor barakae* has been described from the Barak river itself, and *Tor putitora* is an IUCN redlisted 'Endangered' species (Pinder *et al.* 2019).

- **Cost-Benefit analysis**: It is the most important study that should be done for all the HEPs of NE India, since the environmental impacts of such hydel projects are permanent and nearly irreversible. Further, hydrological and socio-economic impacts are even more severe, threatening water and food security, and causing internal displacement, poverty, *etc*. If not done properly, years into the future, we may have to remove such HEPs to restore lost ecology, hydrology and economy, as being done by the US (Purtill, 2012).
- **Reducing hazards**: The NE India falls in high seismic zone, having active faults, with devastating earthquakes every now and then. Thus, large hydel projects are prone to dam bursts and may cause reservoir-induced seismicity. As such, it is essential that the project sites should be appropriately chosen so as to be as distant from active faults as possible. Basin-wide management should be taken up by all the states as well as the upstream and downstream riparian nations in order to mitigate floods, effectively distribute water resources for maintaining ecological flow and sediment flux.

CONCLUSION

The present study estimated the submergence area of one of the most controversial HEPs of NE India, the Tipaimukh project, using GIS modeling. Based on the findings, power density and emission of GHGs from the reservoir of the project was estimated, in order to determine carbon emission reduction credits of the project. The submergence area was found to be 331.31 sq. km., 73.433% of which being forest land timid with wildlife assemblage. The larger and disproportionately high reservoir surface area implies that the project would produce large amount of GHGs. In addition, the submergence area of the project includes homestead and cultivable land where the local tribes perform agriculture, forestry, horticulture, *etc.*, and is thus linked to their livelihood. Further, the submergence area includes sites of religious and cultural importance. It is feared that if the project is ever built, it would badly affect the socio-economy, livelihood and religious and cultural sentiments of the indigenous people. It has been found that if the height of the project is reduced to 120 m, the submergence area as well as emission of GHGs may be reduced by upto 44.23%. This would minimize the bio-physical and socio-economic impacts of the project at project site, upstream submergence area and downstream.

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