Big concerns with small projects: Evaluating the socio-ecological impacts of small hydropower projects in India

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4 authors:

Suman Jumani
Network for Engineering With Nature (NEWN)

Shishir Rao
University of Georgia

Siddarth Machado
The Nature Conservancy

Anup Prakash

Ambio
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KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

REPORT

Big concerns with small projects: Evaluating the socio-ecological impacts of small hydropower projects in India

Suman Jumani, Shishir Rao, Siddarth Machado, Anup Prakash

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Abstract Although Small Hydropower Projects (SHPs) are encouraged as sources of clean and green energy, there is a paucity of research examining their socio-ecological impacts. We assessed the perceived socio-ecological impacts of 4 SHPs within the Western Ghats in India by conducting semi-structured interviews with local respondents. Primary interview data were sequentially validated with secondary data, and respondent perceptions were subsequently compared against the expected baseline of assured impacts. We evaluated the level of awareness about SHPs, their perceived socio-economic impacts, influence on resource access and impacts on human–elephant interactions. The general level of awareness about SHPs was low, and assurances of local electricity and employment generation remained largely unfulfilled. Additionally most respondents faced numerous unanticipated adverse impacts. We found a strong relationship between SHP construction and increasing levels of human–elephant conflict. Based on the disparity between assured and actual social impacts, we suggest that policies regarding SHPs be suitably revised.

Keywords Human–wildlife interactions · India · Mini-hydel dam · Small hydropower projects · Socio-ecological impacts

INTRODUCTION

Growing human populations, rising energy consumption, increasing energy access and industrial expansion are continuously increasing power requirements, especially in developing countries (Ahmad et al. 2014). In the face of these rising needs, issues such as demands for distributed electricity supply, limited reserves of fossil fuels and the imminent threat of global climate change have spurred the growth of renewable energy technologies globally (Ahmad et al. 2014).

Small hydropower is one such form of renewable energy which has witnessed massive growth in the past decade. Typically functioning as run-of-river projects, SHPs broadly have 4 components—a diversion weir, a penstock pipe, a powerhouse with turbines and a tailrace canal. River flows are diverted at the weir, through the penstock pipe, to the downstream powerhouse, where it drives the turbines to produce electricity. Water is then released back into the river channel through the tailrace canal. Widely believed to have no emissions, small areas of submergence and minimal rehabilitation issues, SHPs are propagated as a means to meet rising energy demands without harming the environment (Sharma 2007; Kosnik 2008; Yuksel 2010). Further, SHPs assure social benefits such as employment generation, development of fisheries, infrastructure development and electrification of remote areas, and therefore claim to be socially beneficial (Chaurey et al. 2005; Balat 2007). Based on the presumption that SHPs are environmentally sustainable, socially equitable and financially viable, their growth is being globally encouraged through facilitative policies, international carbon credits and monetary incentives (Nautiyal et al. 2011; Liu et al. 2013).

However, scientists have cautioned against labelling the entire sector as environmentally benign (Abbasi and Abbasi 2011; Kibler and Tullos 2013) since the definition of SHPs varies across countries, ranging from a maximum generating capacity of 1 megawatt (in Denmark) to 50 megawatt (in China). Additionally, key factors are often overlooked when assessing their impacts, such as altered flows, barriers to

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animal movement, effects of ancillary structures and impaired sediment transport (Gleick 1992; Başkaya et al. 2011; Anderson et al. 2014; Pang et al. 2015). Recent studies indicate that assessing SHPs as isolated entities without recognising their cumulative impacts precludes a holistic understanding of their environmental, economic and social consequences (Abbasi and Abbasi 2011; Kibler and Tullos 2013). Additionally the trickle down of socio-economic benefits to local communities is also being questioned due to the lack of accountability and monitoring (Schmitz 2006).

In India, the Ministry of New and Renewable Energy (MNRE) defines SHPs as those that produce between 2 and 25 megawatts of power. Unlike other hydel projects, SHPs in India are exempted from requiring environmental clearances due to the assumption that they have negligible adverse effects. Hence they do not partake in public hearings, social assessments and environmental impact assessments (as per the Environmental Impact Assessment Notification of 2006). Their growth is further encouraged through governmental financial assistance (Ghosh et al. 2012; MNRE 2015). India has tapped about 20% of its small hydropower capacity, and there is now a gathering momentum to realise its full potential. Consequently, almost all rivers that flow through the country have been dammed, with highest densities in 2 global biodiversity hotspots—the Western Ghats and the Himalayas (Myers et al. 2000).

Various study reports and Clean Development Mechanism Project Design Documents (CDM-PDD) of SHPs in India assure socio-economic benefits to local communities. However, rising incidents of social conflict due to SHP development are being highlighted through journal articles (Erlewein 2013; Baker 2014), reports (Bhaumik 2012) and court petitions (Atul Bhardwaj v. HPPCB and Ors. 176/2014). In the midst of these contradictory narratives, there exists a lacuna in assessing the socio-ecological impact of SHPs on local communities. In an attempt to address this gap, we focus on understanding the perceptions of a local community with regard to (1) awareness about SHPs, (2) socio-economic impacts of SHPs, (3) impacts of SHPs on resource access and (4) impacts of SHPs on human–wildlife interactions. We also compare respondent perceptions against the expected baseline of assured impacts. In doing so, we provide recommendations that could facilitate the sustainable growth of this sector, particularly in landscapes that are of significant conservation importance.

MATERIALS AND METHODS

Study area

We conducted our study around the upper reaches of the Gundia River basin, an important tributary to the west-flowing Netravathi River of Karnataka State in India. This region constitutes part of the Western Ghats—one of the 8 hottest hotspots in the world (Myers et al. 2000) characterised by exceptionally high levels of species richness, endemism and anthropogenic pressures. The study site includes the Kemphole, Kagneri and Kanchankumari Reserve Forests, and extends from 12°45′N to 12°56′N latitude and 75°36′E to 75°47′E longitude encompassing an area of 252.6 km^2. The Reserve Forests comprise evergreen and semi-evergreen forests interspersed with grasslands. Outside the Reserve Forests, the landscape is primarily composed of a matrix of forest patches, plantations, agricultural fields and settlements. The region receives a mean annual rainfall of 3750 mm (Ramachandra et al. 2015). Previous assessments have recorded the presence of 56 fish species, 23 amphibian species and 22 mammalian species (Dudani et al. 2010). This area is part of an important elephant corridor (Ramachandra et al. 2010) and is listed as a potential freshwater key biodiversity area (Molur et al. 2011).

The stretch of river adopted for the study extends for 71.5 km and has a cluster of 4 SHPs along its course. Project characteristics of the SHPs are listed in Table 1. All 4 SHPs are registered with the Clean Development Mechanism (CDM) of the Kyoto Protocol. This enables them to earn Certified Emission Reduction units which may be traded in emissions trading schemes.

Twenty-one river-dependent communities are located within a 6 km radius of the SHPs (Fig. 1), most of which fall within the Eco Sensitive Area of the Western Ghats (Kasturirangan et al. 2013). The community is dominated by the '*Vokkaliga*' caste—a Hindu caste group primarily engaged in agricultural activities. People depend on perennial springs and groundwater reserves to meet their drinking-water needs, and utilise the main river for irrigation, subsistence fishing and other domestic activities. Most people have small-scale land holdings and depend on agriculture and associated activities for their livelihood.

Study design

Semi-structured interviews were used to gather respondent perceptions on the impacts of SHP development as this method is well suited for exploring perceptions regarding sensitive issues. It also allows for probing and clarification of answers (Bariball and While 1994), which aids in establishing an interviewer–respondent rapport, thereby reducing the risk of receiving socially desirable answers (Patton 1990).

To address the drawbacks of semi-structured interviews with regard to reliability of data (Diefenbach 2009), we adopted a measure of quantitative triangulation (Bamberger et al. 2011) where primary interview data were

Table 1 Characteristics of SHPs

SHP name	Installed capacity (MW)	Dam height (m)	Year of commissioning	Ownership	Status
Yettinahole mini-hydel scheme	3	NA	2010	Private	Grid-connected
Kadamane mini-hydel scheme-1	9	21.85	2008	Private	Grid-connected
Kadamane mini-hydel scheme-2	15	14.5	2010	Private	Grid-connected
Kemphole mini-hydel scheme	18	21	2005	Private	Grid-connected

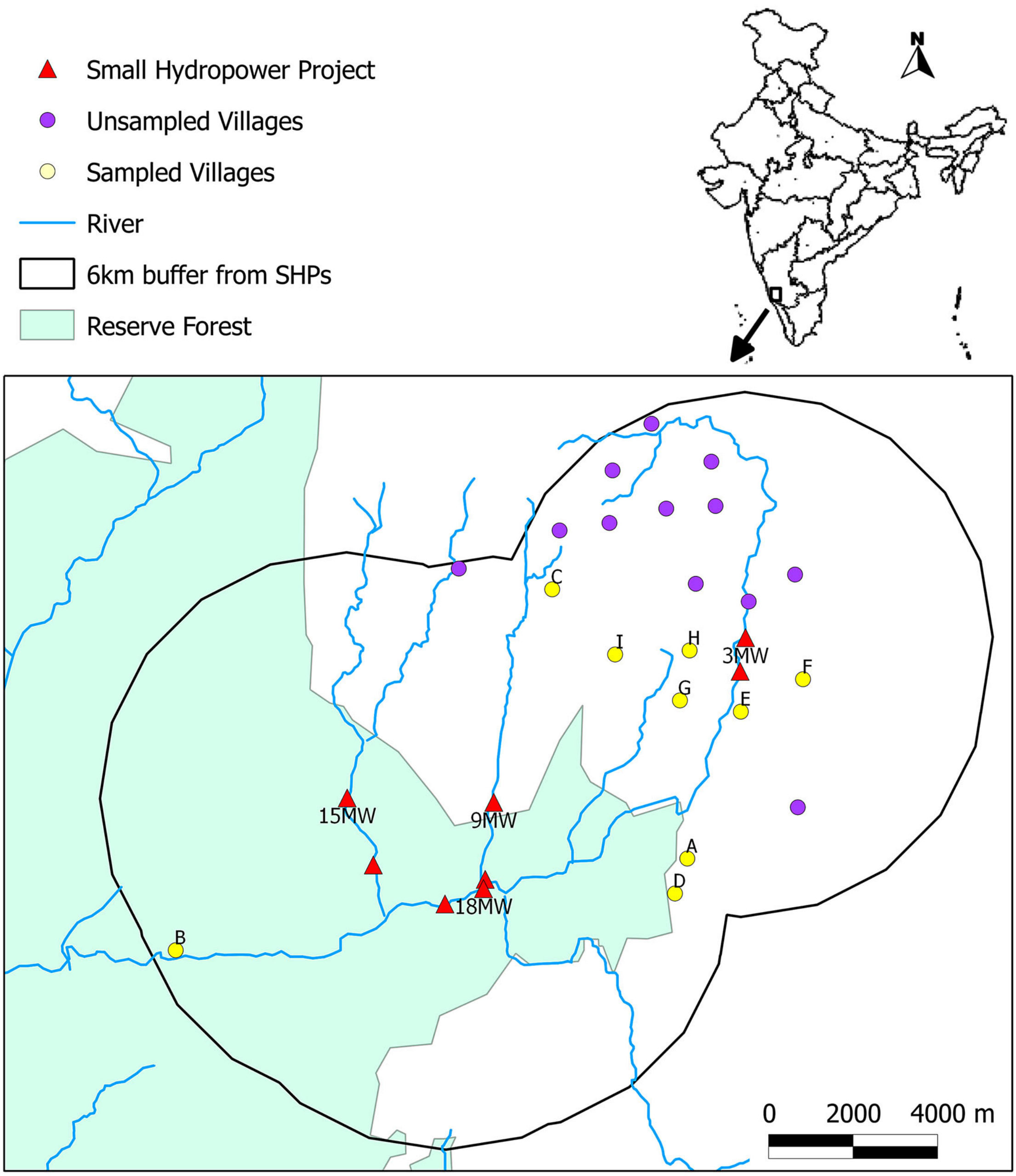

Fig. 1 Map of study site. Note that the illustration of India is not to scale

sequentially validated with reliable secondary data. The use of secondary information also served to contextualise our sample against the wider population.

Respondent perceptions were compared against the expected baseline of assured impacts, which were obtained from the CDM-PDDs of the projects.

Field surveys

We conducted 73 semi-structured interviews across 9 of the 21 villages located in the study area between June and August 2014. Three estate villages were not sampled as most of the inhabitants consisted of labourers hired from outside this region. The northern-most communities were also not sampled since they were located near the headwaters of the main river, far above and beyond the influence of the SHPs. Care was taken to sample communities housing village council or *panchayat* offices (F and H), large communities of local importance (A, D and G) and smaller remote communities (C and E). The final questionnaire was designed after a pre-test. Respondents included members of the local community who resided and worked within the landscape, and were chosen using a combination of opportunistic and snowball sampling methods. Respondents were informed about the study and their verbal consent was obtained prior to the interview. Interviews were conducted in the local language, Kannada, and recorded on a voice recorder when permitted. Each interview took 50 to 60 min, and the final questionnaire consisted of 30 closed-ended questions, multiple contingency questions and 3 open-ended questions, categorised into 4 sections that sought information on:

1. Awareness and participation: (a) When and how people were informed about SHPs, (b) whether their concerns were sought and addressed, and (c) whether *panchayat* permission was awarded readily.
2. Socio-economic impacts: Respondent perceptions on the impact of SHPs on (a) employment opportunities, (b) electricity supply, and (c) effect of dam-related infrastructure.
3. Resource access and water issues: Respondent perceptions on the impact of SHPs on (a) access to surrounding forests, roads and rivers, (b) freshwater fish assemblages and fish catch, (c) river water quality, and (d) the effect of sporadic water releases from the dams.
4. Human–elephant conflict (HEC): This section was added following our pilot surveys, specifically designed to obtain information on trends in HEC (damage to crop, property and life) over time.

The issue of SHP development in this region is a contentious one. The sensitive nature of the topic coupled with resource constraints led to a moderate coverage of just 73 interviews.

Secondary data collection

To enhance the validity of the interview data, secondary data from reliable sources were collected to look for converging or diverging trends. Baseline information on assured social benefits was obtained from CDM-PDDs of the 4 SHPs. News coverage and video recordings were used to validate respondent claims. Video recordings have not been shared to preserve respondent anonymity. Temporal trends in HEC were explored by collecting quantitative data on elephant-related compensation claims for damages to crop, property and life filed by local people in the region. These data were procured for the period between 1999 and 2013 from the State Forest Department. Information obtained from the Karnataka Renewable Energy Development Limited was used to determine the date of commissioning of the SHPs in the study area.

Analytical methods

Interview responses were analysed in R v.3.0.1 (R Development Core Team 2013). Villages and rivers were digitised using Quantum GIS v.1.8.0 (Quantum GIS Development Team 2012).

Descriptive statistics were used to analyse the perceived impacts of SHPs. Responses to the close-ended questions pertaining to each category of the 4 sections were coded into values of -1, 0 or $+1$ to indicate a perceived negative, neutral or positive impact, respectively. For example, reduced access to river stretches due to SHPs was scored -1; no impact of SHPs on river access was scored 0; enhanced access to river resources was scored $+1$. Scores were condensed into 6 categories, normalised to a range of -1 to $+1$ and calculated for each respondent. Averaged scores across categories for each village, portrayed as a bar plot, indicate the extent of perceived positive (0.1 to 1), neutral (0) and negative (-0.1 to -1) impacts.

The drivers of respondent perception were examined by constructing regression trees using the R package '*party*' (Hothorn et al. 2006). The above-calculated perception scores for each respondent were tested against 6 predictor variables—(1) age, (2) caste, (3) source of income, (4) employment status, (5) previous employment at SHPs and (6) fishing frequency. Similarly, to examine the relationship between HEC and SHP constructions we constructed a classification tree using the R package '*tree*' (Ripley. 2016). The sudden onset of HEC ("HEC" or "NO HEC") was tested against 4 predictor variables—(1) agricultural land holding, (2) proximity to nearest SHP, (3) distance to river and (4) distance to forest. Agricultural land holding referred to whether respondents owned agricultural lands or plantations. Distance to the closest SHP, river and forest edge was computed for every respondent based on village location. To build a tree, the response variable is repeatedly partitioned into subsets based on its relationship with the predictor variables (De'ath and Fabricius 2000). Each split is based on the predictor variable that results in the greatest change in explained deviance. A 10-fold cross-validation technique was used to prune the tree and the minimum cross-validated deviance occurred with 2 splits.

RESULTS

Almost all respondents (98.6%) were men as women generally refused to participate in the interviews. The age of respondents ranged from 24 to 78 years (mean = 49 years). We provide additional information on respondent demographics in Table 2.

While respondents from 6 of the 9 surveyed communities perceived some level of socio-economic benefits from SHP development, the overall perception regarding their impact on all other categories was predominantly negative (Fig. 2). There were no significant factors that significantly explained the overall perception of SHPs in the study area.

Awareness about SHPs

Although stakeholder consultation with local communities is not mandated as per Indian policy, it is a prerequisite for SHPs registered as CDM projects. All respondents reported an absence of stakeholder consultations, and stated that they were neither informed nor consulted prior to dam construction (Table 3). This was contrary to the information provided in the CDM-PDDs, which stated:

> All stakeholders (including residents of the neighbouring villages) had really shown their pleasure and support to the project activity (Appendix S1).

About 47% of the respondents were unaware that their *panchayat* had awarded No Objection Certificates for the dams to be built. Many respondents (31.5%), including 4 *panchayat* members, admitted that the process of SHPs seeking *panchayat* permission was pretence, driven largely by bribes and political pressures, rather than the intent to improve social welfare and livelihoods.

Socio-economic impacts of SHPs

Employment opportunities

Despite owning agricultural fields or plantations, most respondents sought additional sources of employment. Most respondents maintained that they did not get an opportunity to work at the dam, despite being assured of the same by dam developers (Table 3). Those who received employment with the dam belonged to 5 of the 9 villages surveyed. A small proportion of the respondents received temporary and daily-wage employment. Temporary employment mostly constituted security duty, ranged between 2 months to 4 years, and paid a salary of 50USD to 60USD per month, which is below the minimum wages mandated by the government (The Minimum Wages Act 1948). Daily-wage labour existed predominantly during the construction phase and paid approximately 4USD to 8USD per day.

Seven of the 10 respondents who were hired as temporary employees believed that they were underpaid, whereas 6 of the 7 respondents employed as daily-wage labourers were satisfied with the wages received, but found the job duration to be short. Only 1 respondent was awarded permanent employment which he voluntarily terminated after 1 year due to insufficient wages.

Table 2 Characteristics of villages and respondents

Village	No of respondents	Age in years Range (mean age)	Distance in km to the nearest			Electricity supply in hours/day mean (range)	
			Forest edge	River	SHP	Monsoon	Non-monsoon
A	11	26–65 (51)	0.25	1.0	4.53	7 (2–20)	16 (12–24)
B	5	26–53 (39.5)	0.0	0.1	5.50	0	0
C	2	65–49 (57)	3.08	0.54	4.79	4.5 (4–5)	13.5 (12–15)
D	7	34–72 (48)	0.18	1.75	4.40	4.75 (3–7)	11.6 (10–12)
E	4	26–52 (34)	2.60	0.20	0.95	11.2 (5–15)	16 (12–20)
F	9	30–78 (51)	4.12	1.32	1.34	5 (2–15)	12 (5–20)
G	25	24–73 (49.5)	2.31	0.42	1.60	4 (2–10)	10.5 (3–22)
H	4	36–50 (44.5)	2.85	0.30	1.39	3.5 (2–4)	8.2 (5–10)
I	6	49–67 (59.5)	1.40	1.30	3.11	4.4 (2–6)	9 (8–10)
Total	73	24–78 (49)				4.9 (0–20)	10.8 (0–24)

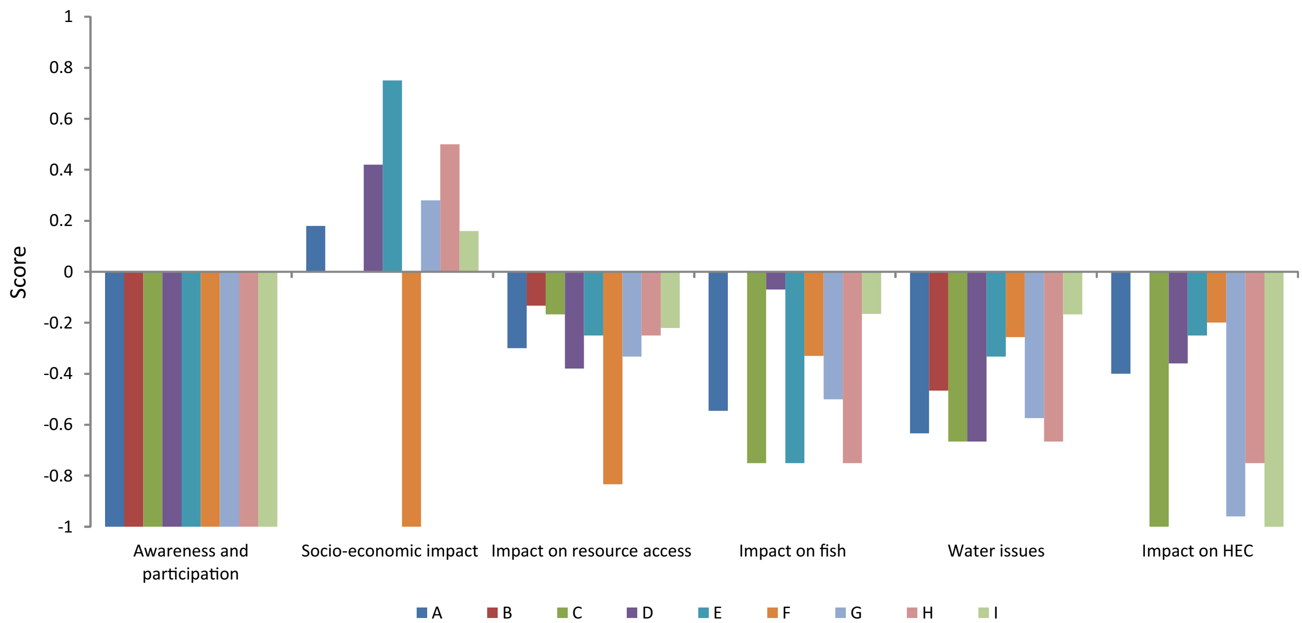

Fig. 2 Perceived impacts of SHPs across villages

The assurance of local employment generation by SHP developers was confirmed by their CDM-PDDs, which stated:

> The mini hydel project contributes to social wellbeing because it generates direct and indirect employment to the local people… The villagers and the office bearers expressed their pleasure with the setting up of the power project as it had provided the rural population with permanent employment opportunities (Appendix S2).

Non-locals were perceived as preferred employees in working plants by all respondents, even for unskilled labour such as cleaning and maintenance. About 58% attributed this to vigilant behaviour of local employees in reporting illegal activities undertaken by dam authorities (for example: sand mining and timber felling). These claims were partly supported by a local news article (Appendix S3). Another 24% attributed this preference to lower risks of strikes and unions with non-locals as compared to local workers.

Over 22% of respondents had participated in mass agitations to demand for employment at the dams. The occurrence of these protests was verified by video footage provided to us by an ex-*panchayat* member.

Electricity supply

Eight of the 9 surveyed villages were electrified prior to SHP construction; 1 village continued to remain un-electrified even after the SHP commissioning. The perceived average electricity supply per day across villages was about 5 h in the monsoon months (June to September) and 11.6 h in the non-monsoon months (October to May) (Table 2). All but one respondent indicated that electricity supply had neither increased nor stabilised post SHP construction, and their expectations of improved electricity supply had not been met (Table 3). This was in contradiction to the CDM-PDDs, which proclaimed:

> With the project activity local people could benefit from increased grid stability, which directly influences rural life quality. The project activity would increase the availability of power in the local area (Appendix S4).

Benefits from dam-related infrastructure

The construction of all 4 SHPs was accompanied by the building of new approach roads, bridges, foot trails and transmission lines. All respondents reported that they did not benefit directly or indirectly from this infrastructure, since they were denied access to these amenities (Table 3). In fact, respondents from village '*F*' got into conflict with dam developers following the construction of transmission towers on their land, which, they claimed exposed them to health risks and reduced the economic value of their land. Respondents from this village further maintained that about 15 village members were arrested for protesting the construction of the transmission towers. This claim was supported by a regional news article (Appendix S5).

Table 3 Respondent perceptions to the impacts of SHPs

Impact	Percentage respondents
Awareness	
Informed	
Informed by relevant authority	0
Not informed by relevant authority	100
Concerns addressed	
Concerns addressed by relevant authority	0
Concerns not addressed by relevant authority	100
Socio-economic impacts	
Employment status	
No employment opportunity	75.34
Temporary employment received	13.7
Daily-wage employment received	9.59
Permanent employment received	1.37
Electricity supply	
Decreased/destabilised after the SHPs	0
No effect	98.63
Increases/stabilised after the SHPs	1.37
Infrastructure	
Has benefitted locals	0
Has not benefitted locals	89.1
Has harmed locals	10.9
Resource access	
River access	
SHPs have enabled access	0
SHPs have restricted access	87.6
No effect of SHPs on river access	12.4
Forest access	
SHPs have enabled access	0
SHPs have restricted access	12.4
No effect of SHPs on forest access	87.6
Road access	
SHPs have enabled access	0
SHPs have restricted access	10.9
No effect of SHPs on road access	89.1
Impact on fish assemblages	
Fish abundance	
Positively affected	0
Adversely affected	73.9
Not affected	26
Average fish size	
Positively affected	0
Adversely affected	13.7
Not affected	86.3
Fish species richness	
Positively affected	0
Adversely affected	1.37
Not affected	98.63
Water issues	
Drinking water	
Positively affected	0
Adversely affected	0
Not affected	100
River water quality	
Positively affected	0
Adversely affected	38.3
Not affected	61.7
Varying water levels	
Dangerous	61.6
Nuisance	8.2
No effect	30.2
Human–elephant interaction	
Human–elephant conflict	
No conflict with elephants	12.4
Recent onset of conflict with elephants	83.5
Continuing historic conflict with elephants	4.1

Resource access and water issues

Most respondents did not experience any change in the ease of accessing surrounding forests due to SHP construction. Respondents from village '*F*' (11%) lost access to a frequently used road which connected their village to the National Highway, since the road now passed through privately owned and restricted dam property. Access to the river was most severely affected, with 88% of respondents claiming to have lost access to river stretches which previously served as locations for sustenance fishing (Table 3). After SHP commissioning, the stretch of the river extending from the reservoir to the tailrace canal, cumulatively amounting to 7.4 km (or 10.35% of the river length), fell within restricted areas and became inaccessible to the local community.

About 68.5% perceived a decline in fish abundance and attributed it, in part or whole, to the proliferation of SHPs. They claimed that this decline directly affected their fish catch. However, most respondents did not perceive any impact of SHPs on average fish size or fish species richness (Table 3).

Since none of the respondents depended on the main river for water consumption (drinking), SHPs had no effect on the drinking-water supply. Most respondents did not perceive any effect of the SHPs on river water quality. However, about 40% believed that river water quality had declined after dam construction as the water accumulated sediment when stagnant, got muddy during release and made the rocks more slippery due to sediment deposits (Table 3).

Respondents explained that river flows were highly pulsed below the powerhouse, and that the sudden release of water did not follow a fixed timetable and was not accompanied by warning signals. While about 30% remained unaffected by the sporadic release of dam water, about 8% indicated that it posed a nuisance, since it hampered river crossings and/or washed away fishing nets. However, 62% considered it to be dangerous for people and cattle, as there were instances of people and cattle getting washed away (Table 3). While we were unable to locate any secondary information linking such incidents with the 4 SHPs of interest, we found media articles reporting the death of 3 students in the Netravathi River due to water release from another SHP—AMR Shamboor—located about 70 km downstream of our study site (Appendix S6).

Impacts of SHPs on human–elephant conflict (HEC)

While respondents from community '*B*' experienced no HEC, almost all respondents from other villages reported significant levels of HEC (Table 3). About 84% claimed that elephants rarely or never entered their villages in the past, and that HEC had increased only in the last decade. The predominant reason given for this sudden onset of HEC (71.5%) was the proliferation of SHPs in the landscape (Fig. 3). When asked to describe how SHPs could increase HEC, the following reasons were given:

a. Disturbances caused by sound, light and people movement in forests during dam construction and operation have triggered elephant movement towards villages ($n = 42$).
b. Dams have destroyed riparian vegetation, especially bamboo—a critical food source for elephants. Hence they have started moving towards villages in search of food ($n = 19$).
c. Linear intrusion such as canals and penstocks have blocked elephant movement corridors ($n = 11$).

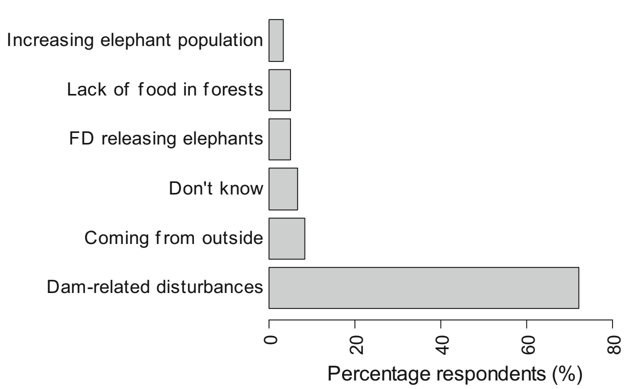

Fig. 3 Perceived reasons for the sudden increase in HEC

Based on these observations, we examined the relationship between HEC and SHP construction. Elephant-related compensation claims peaked thrice between 1999 and 2013. The observed peaks in 2005, 2008 and 2010 coincided with the construction of 1 (18 MW), 1 (9 MW) and 2 (15 MW and 3 MW) SHPs, respectively (Fig. 4). The peaks showed an increase in filed compensation claims by 173, 97 and 22.5% compared to respective previous years. Fifty per cent of the respondents reported that HEC began between 2004 and 2006, and this coincided with the first peak in filed compensation claims (Fig. 4).

We further tested this relationship using a classification tree. The tree classified our response variable into 3 classes using 2 of the 4 predictor variables—agricultural land holding and proximity to SHPs (Fig. 5). The model indicated that almost all respondents who owned agricultural lands experienced a sudden increase in HEC. For others, proximity to the closest SHP influenced the response, with all respondents at a distance of less than 5 km from the dam experiencing a sudden increase in HEC (Residual mean deviance = 0.39).

DISCUSSION

Implications of findings

The lack of expected benefits from the dams coupled with the onset of unexpected adverse impacts led to high levels of dissatisfaction among respondent over the construction of SHPs in the region.

Benefits assured to local communities in CDM-PDDs, such as improved socio-economic well-being, rural electrification and benefits from dam-related infrastructure did not materialise. Local employment, if any, was largely temporary, limited to the early stages and remunerating below the minimum mandated wages. Perceived adverse impacts such as the sudden onset of HEC, sporadic water releases, declining fish abundances and restricted access to previously accessible natural resources further increased local hostility against the SHPs.

Our study is the first to illustrate a strong correlation between the onset of HEC and SHP construction. The high degree of overlap between periods of actual and perceived increase in HEC and periods of SHP construction, suggest that SHPs in elephant habitats can trigger or increase conflict. In our study, the number of conflict claims increased from an annual average of 248 claims pre-dam

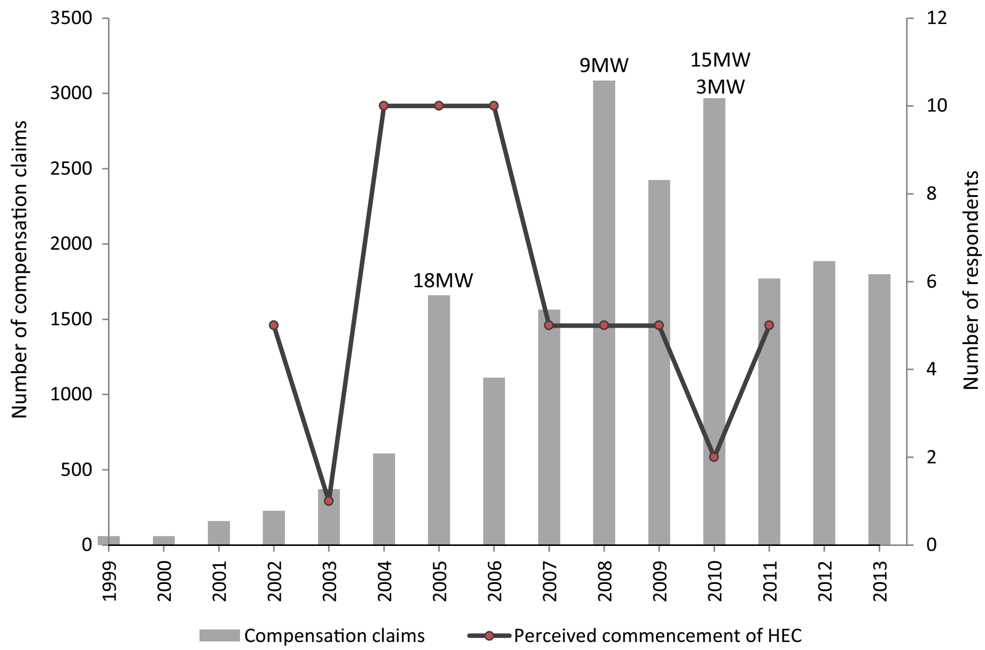

Fig. 4 Relationship between perceived and actual HEC levels and periods of SHP construction. The *grey bars* indicate the number of filed compensation claims. The *black line* indicates the perceived time period of commencement of HEC. The period of construction of each SHP is represented by the capacity (in MW) above the corresponding year

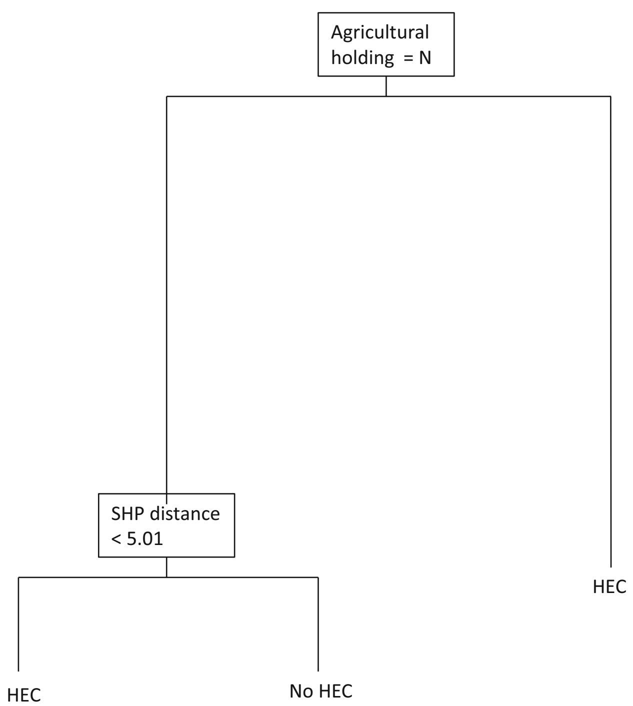

Fig. 5 Classification tree modelling the sudden onset of HEC against agricultural land holding and proximity to closest SHP

construction (1999 to 2004) to 2030 claims post-dam construction (2005 to 2013). The converging lines of evidence from primary interview data and secondary government data strengthens the reliability of our results. The study site, which comprises part of an elephant corridor, is characterised by steep terrain, which poses a natural constraint for elephant movement (Wall et al. 2006). Hence the proliferation of SHPs and their associated structures can further disturb and obstruct the free movement of elephants, possibly leading to increased HEC as elephants are forced to move into new areas (Fernando et al. 2010). Conspicuous increase in HEC during periods of dam construction can be attributed to extensive blasting, working of heavy machinery and vehicular movement during this phase. Similar trends of habitat avoidance were observed in African forest elephants (*Loxodonta africana cyclotis*) in response to dynamite explosions associated with oil prospecting in Gabon (Rabanal et al. 2010). Though HEC decreased post construction, it remained significantly higher compared to the period prior to dam building. This can be attributed to operational disturbances, human activity, forest fragmentation and SHP-related infrastructure development. This is supported by the report of the Karnataka Elephant Task Force (2012) which states that SHP construction can increase HEC levels by causing disturbance in elephant habitat and hindering elephant movement. Similar trends were observed along the Chilla–Motichur elephant corridor, where elephant movement was drastically affected by large hydropower development (Johnsingh and Joshua 1994).

As illustrated in our study, the transfer or lease of land and river resources to private SHP developers, with little or no community consultation, can strongly infringe upon the rights of local communities (Islar 2012). Since SHPs alter natural flow patterns, they have been known to directly disrupt culturally important sites, traditional irrigation cycles, watermills and drinking-water sources (Reddy et al. 2006; Baker 2014). Their impact on longitudinal riverine connectivity further affects fish populations, and thus local fishing communities. The lack of public consultations may explain why factors such as restricted access to natural resources, sporadic water releases and disruption of river flows were not mentioned in even a single CDM-PDD. Our results concur with assessments by Schmitz (2006), which indicates that the predominant reason for SHPs not contributing to sustainable development is the lack of public participation.

Though our study is limited by a moderate sample of 73 interviews, high levels of corroboration between primary and secondary data improve the reliability of our results. Constrained by our sample size, we were unable to examine the geographic and spatial parameters that influenced the relationship between HEC and SHPs. Further research is required to examine the impacts of individual SHPs vis-à-vis the cumulative impact of multiple SHPs, and the relationship between SHPs and human–animal interactions across different landscapes.

Policy recommendations

SHPs are usually subject to minimal scrutiny, especially in developing countries striving to meet distributed energy demands, such as China, India, Turkey and Brazil (Haya and Parekh 2011). For example, the exemption of SHPs from requiring Environmental Clearances in India has resulted in their proliferation. Until 2012 India's MNRE had commissioned 1266 SHPs and identified 6474 sites for SHP development, all without any impact assessments or public consultations. Within the Netravathi River basin at least 10 SHPs have been commissioned and 44 more are in the pipeline. This excludes mid-sized and large-sized dams. India's draft National Mission on Small Hydro (2015) is proposing a number of economic and policy incentives to promote this sector. However, it still does not acknowledge the sector's adverse social and environmental consequences.

Local stakeholder consultations provide a platform to identify and remediate areas of conflict or concerns prior to dam building, and constitute an essential tool to facilitate transparent and participatory decision making (Millennium Ecosystem Assessment 2005). SHPs should be subject to prior environmental impact assessments, especially since environmental degradation can strongly affect the health and socio-economic activities of local communities. For example, the disruption of riverine connectivity by SHPs can negatively impact fish communities, thereby affecting local fish catch; the regulation of riverine flows can disrupt local water use patterns; deforestation and fragmentation due to infrastructure development can impact wild animal movement, thereby increasing human–wildlife conflict.

More important than strengthening the policies governing individual projects is the need to address the cumulative effects of multiple SHPs. Recent studies indicate that when normalised for power output, the impacts from extensive SHP development can be more serious than large hydropower systems (Abbasi and Abbasi 2011). Hence, cumulative impact assessments can aid in the landscape-level planning of SHP development by estimating basin-wide carrying capacities, minimum mandated environmental flows and inter-dam distances.

Additionally, the implementation of effective monitoring mechanisms coupled with regulations promoting decentralised electricity supply, local employment at working plants and participatory management practices can enhance compliance with standard baselines and policies.

CONCLUSION

Our findings complement a growing volume of scientific literature that makes evident the fact that SHP development is not necessarily equivalent to low-impact hydropower development. We found that the lack of adequate scrutiny within this sector has resulted in a near absence of public participation, false claims being made in project reports and high levels of conflict with local communities.

Given the ambitious targets of projected SHP growth, there is a dire need for further research, especially to better understand their cumulative ecological and social impacts. Suitable policies, science-based decision making, compliance with sustainability protocols (such as the IHA Sustainability Assessment Protocol) and effective monitoring can aid in the development of low-impact small hydropower projects and ensure that the true potential of this sector is realised.

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AUTHOR BIOGRAPHIES

Suman Jumani (✉) is a Senior Research Fellow with the Foundation for Ecological Research, Advocacy and Learning (FERAL), Bangalore, India. Her research interests include freshwater ecology, with a focus on applied interdisciplinary research.
Address: Foundation for Ecological Research, Advocacy and Learning, Bangalore, India.
e-mail: sumanjumani@gmail.com

Shishir Rao is a Research Consultant with the Wildlife Conservation Society-India, Bangalore. His research interests include freshwater ecology, herpetology and the social sciences.
Address: National Centre for Biological Sciences, Bangalore, India.
e-mail: shishir.t.rao@gmail.com

Siddarth Machado is a Junior Research Fellow at the National Centre for Biological Sciences (NCBS), Bangalore, India. His field of interest lies in ecosystem services, restoration ecology and conservation biology.
Address: National Centre for Biological Sciences, Bangalore, India.
e-mail: siddarthmachado@gmail.com

Anup Prakash is the Field Director of Agumbe Rainforest Research Station of the Madras Crocodile Bank Trust (MCBT), India. His research interests include road ecology, carnivore ecology and natural history.
Address: Agumbe Rainforest Research Station, Agumbe, Shimoga District, India.
e-mail: anup.bp@gmail.com